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A COST-BENEFIT ANALYSIS OF POWER QUALITY MANAGEMENT IN THE AVIONICS REPAIR FACILITY

by

Brad E.Valdyke

March 1998

Principal Advisor:	Katsuaki L. Terasawa
Associate Advisor:	Keebom Kang

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This thesis focuses on improved aviation readiness and reductions in pipeline investment and repair costs brought about by a power quality management program. Using cost-benefit analysis, it isolates the effects of an implemented program at an Aircraft Intermediate Maintenance Department in order to quantify and compare the costs of implementation and the benefits gained. Specific attention is given to reduction of repair cost of Automatic Test Equipment, and reduction of repair Turn Around Time of repair processes utilizing Automatic Test Equipment. Our analysis identified three-year savings of up to $1,135,134 through the application of a power quality management program at one repair location. The analysis demonstrates the savings achievable from the management of power quality in processes using sensitive electrical equipment.

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Brad E. Valdyke
Major, United States Marine Corps
B.S., Georgia Institute of Technology, 1985

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March 1998

Author: Brad E. Valdyke

Approved by: Katsuaki L. Terasawa, Principal Advisor

Keebom Kang, Associate Advisor

Reuben T. Harris, Chairman
Department of Systems Management

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This thesis focuses on improved aviation readiness and reductions in pipeline investment and repair costs brought about by a power quality management program. Using cost-benefit analysis, it isolates the effects of an implemented program at an Aircraft Intermediate Maintenance Department in order to quantify and compare the costs of implementation and the benefits gained. Specific attention is given to reduction of repair costs of Automatic Test Equipment, and reduction of repair Turn Around Time of repair processes utilizing Automatic Test Equipment. Our analysis identified three year savings of up to $1,135,134 through the application of a power quality management program at one repair location. The analysis demonstrates the savings achievable from the management of power quality in processes using sensitive electrical equipment.

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LIST OF ACRONYMS

AC	Alternating Current
ADT	Administrative Delay Time
AIMD	Aircraft Intermediate Maintenance Department
A_O	Operational Availability
ATE	Automatic Test Equipment
ATS	AN/USM-470(V)1 Avionics Test Set
AWP	Awaiting Parts
BCM	Beyond Capability of Maintenance
DC	Direct Current
D-Level	Depot Level
DoD	Department of Defense
EPIC	Electrical Power Interface Compatibility
EPRI	Electric Power Research Institute
ESD	Electrostatic Discharge
FTSCPAC	Fleet Technical Support Center, Pacific
FYDP	Fiscal Year Defense Program
GAO	General Accounting Office
IEEE	Institute of Electrical and Electronics Engineers
I-Level	Intermediate Level
LDT	Logistics Delay Time
M	Mean Active Maintenance
MAF	Maintenance Action Form
MALS	Marine Aviation Logistics Squadron

MDT	Mean Down Time
MOBF	Mean Output Between Failure
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
NACA	NALCOMIS AIMD Cost Accounting
NADEP	Naval Aviation Depot
NALDA	Naval Aviation Logistics Data Analysis
NAESU	Naval Aviation Engineering Service Unit
NAMP	Naval Aviation Maintenance Program
NAVAIRSYSCOM	Naval Air Systems Command
NAS	Naval Air Station
NAVOSH	Naval Occupational Safety and Health
O-Level	Organizational Level
OSD	Office Secretary of Defense
PEPSI	Pre-Deployment Electrical Power Survey and Inspection
PW	Public Works
RFI	Ready For Issue
TAT	Turn Around Time
WC	Work Center
WIP	Work In Process
WUC	Work Unit Code

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DoD) today operates in a fiscally constrained environment. Operational assets are fewer, operating budgets are smaller, and procurement spending has dipped to levels that many warn will affect our military's future capabilities. Faced with sustaining a heightened level of readiness abroad, and the need to increase investment in modernization without increasing overall defense budgets, DoD has recently focused on reducing the cost of support operations and their associated infrastructures. The objective is to find ways to provide required support capabilities at reduced costs. To this end, a reduction of logistics infrastructure costs has been mandated. Attainment of savings remain elusive however. According to the GAO, for the fourth straight budget year since 1995, DoD has not met its procurement goals established in previous Future Years Defense Programs* (GAO-Davis, 1997). Not only have the necessary levels of savings not been obtained, but logistics pipelines have also become stressed. Deployments of U.S. forces abroad continue to underline the importance of gaining control over the logistics pipeline.

The task is two fold. First, to operate at less cost, and second to achieve high performance with fewer assets. Dr. Kaminski, then Under Secretary of Defense (Acquisition and Technology), stated in the Department of Defense Logistics Strategic Plan (1995) that "Logistics processes must be as efficient as possible. Shorter lead-times

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* The Future Years Defense Program (FYDP) is the official DoD financial plan which summarizes forces and resources associated with programs approved by the SECDEF over the future six year horizon.

are needed to improve customer confidence in the logistics system." To accomplish this, the strategic plan directs that precedence in allocating resources be given to processes that best support unit readiness. The areas focused on thus far have been inventory and pipeline reduction, and privatization. These concepts are central to logistics, however, and beginnings of organizational change normally occur in the periphery (Barrett, 1998). With this knowledge it should not be a surprise that true logistic infrastructure savings have been elusive. Logistics streamlining remains DoD's most favored option. Resources, however, should be applied to new and varied areas with demonstrated positive return on investment capabilities. Facets of logistics thought not to be in the mainstream really are worthy of further examination. Naval aviation logistics has many examples of small efforts that have had large impacts.

One such unexplored area of savings exists in the realm of Automatic Test Equipment (ATE). Excess costs are likely being overlooked, and achievable operational readiness is likely not being achieved because of a lack of attention to the quality of the electrical power supplied to ATE. Presently, Naval Air Systems Command (NAVAIRSYSCOM) does not ensure electrical power quality standards for ATE, particularly standards of acceptable power inputs and ground connections. A lack of support equipment, procedures, and training in the power quality field has allowed a potential universal degradation of NAVAIR ATE facilities. The management of power quality to ATE presents a process improvement with immediate positive impacts on safety, costs, inventory, and operational readiness.

Already recognizing the potential for improvement, the Aircraft Intermediate Maintenance Department (AIMD) at Naval Air Station Lemoore (NAS Lemoore) instituted a power quality management program in 1995. The preliminary results of their efforts justify action.

B. RESEARCH OBJECTIVE

This research will analyze the cost and benefits of applying electrical power quality management techniques to the AIMD avionics repair process at NAS Lemoore. This research anticipates showing that significant monetary savings can result from small incremental advances in this field. Further, that resulting logistics cycle time reductions can additionally yield pipeline inventory investment reductions. This research will quantify the historical costs of implementing electrical power quality initiatives at NAS Lemoore AIMD, and contrast them to the direct and indirect savings associated.

C. RESEARCH QUESTIONS

Primary Research Question:

- How and to what extent can power quality management improve the process capabilities of the Aircraft Intermediate Maintenance Department's (AIMD) avionics repair facility?

Subsidiary Research Questions:

- What is the current profile of AIMD avionics repair process capabilities?
- What is power quality management?
- What are the current DoD practices to manage power quality?
- What are the current industry power quality best management practices?
- What are the potential results of poor power quality to the avionics repair process utilizing Automatic Test Equipment (ATE)?
- What benefits can be achieved by adopting power quality management practices?
- What actions should DoD pursue to implement power quality management?

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

This thesis is a cost-benefit analysis of implementing power management initiatives at the NAS Lemoore AIMD avionics repair facility. The AIMD represents a job-shop repair process environment, where the output varies from component to component and the activity includes a mix of jobs following different paths through a program network (Blanchard, 1992). Since no two jobs are alike, a grouping of like processes is selected for analysis. This results in conclusions that may more confidently be transposed upon other populations.

The comparison is accomplished in the framework of a before and after treatment cost-benefit analysis. Cost-benefit analysis details the expected benefits and costs of a proposal or action. Ideally, this involves translating each impact into a common measurement, most often dollars, for comparison. Some effects, however, are difficult or impossible to quantify. They can therefore sometimes be difficult to interpret. (GAO-Joyner, 1997) Where necessary, researcher judgment is applied to weight qualitative effects. Qualitative weighing will be identified as such.

Cost-benefit analysis, as applied in this research, will compare process capabilities before and after the implementation of a power quality management program. To perform this comparison, the analysis will baseline the production process and measure actual process changes resulting from initiation of the program. Measured outputs will be compared with respect to their costs, operational readiness, and inventory requirements. Lessons learned will be formalized into recommendations applicable for DoD use. The grouping selected for analysis will be a random sample of Work Unit Codes (WUCs) repaired in Work Center (WC) 650 utilizing the AN/USM-470(V)1 Avionics Test Set (ATS) at the NAS Lemoore AIMD.

E. ORGANIZATION OF THESIS

Chapter II provides an overview of the Naval aviation repair system, and the impact that repair cycle times and inventory levels have on end user operations. Chapter III provides background information of what power quality is, the causes of poor power quality, and the effects poor power quality may induce. Chapter IV describes the methodology of the cost-benefit analysis performed on the power quality management program instituted at NAS Lemoore AIMD. Chapter V presents the data and outcome of the cost-benefit analysis conducted. Chapter VI provides a summary, conclusions, and recommendations.

II. NAVAL AVIATION MAINTENANCE & LOGISTICS

A. NAVAL AVIATION MAINTENANCE CONCEPT

The Naval Aviation Maintenance Program (NAMP) is a three-tiered system. Maintenance performed at each level is based on required capabilities, equipment, and skills. The three levels of maintenance are Organizational (O-Level), Intermediate (I-Level), and Depot (D-Level). Two common measures of effectiveness apply to the three levels. They are the ability to support weapon system availability at the operational level and the cost of support to provide that operational material readiness.

1. Organizational Level Maintenance

Organizational level maintenance is characteristically performed at the operational site by operational personnel. The goal of O-Level maintenance is to support its own day to day operations. O-Level maintenance is normally of the nature of visual inspections, periodic checks of equipment performance, cleaning of equipment, servicing, adjustments, and removal and replacement of components. Removed components, however, are routinely not repaired at this level, but forwarded to the intermediate level. O-Level maintenance has little ability to impact the inherent cycle time of the repair process, but benefits the most from its reduction. "Operational requirements and unit readiness demand that support at the operational level be the prime focus of logistics (OSD, 1995)."

2. Intermediate Level Maintenance

Intermediate Level maintenance of aviation components for the Navy is performed at the Aircraft Intermediate Maintenance Department (AIMD), and for the

Marine Corps at the Marine Aviation Logistics Squadron (MALS). The I-Level generally repairs components removed by O-Level maintenance. This is accomplished by the removal and replacement of major modules, assemblies, or piece parts to a level greater than that of the O-Level. Higher personnel skills, additional test equipment, more spares, and better facilities enable this increased level of repair. The I-Level mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely material support at the nearest location with the lowest practical resource expenditure. Being on-site, I-Levels are located ashore and at sea where operational squadrons are based. There are 81 Navy AIMDs, and 34 MALS and MALS detachments operating world wide (NSLC 4790.A7065-01, 1996).

3. Depot Level Maintenance

The depot level of maintenance constitutes the highest level of maintenance, accomplishing repairs beyond the capabilities of the I-Level. NAVAIR operates three full Naval Aviation Depots (NADEPs) within the continental United States and two fleet repair sites overseas (Mooney and Sanchez, 1997). Concerning avionics repair, these sites utilize much of the same ATE as the I-Level, but posses the capability to repair components beyond that of the I-Level by virtue of personnel skill levels, additional component repair equipment, and whole weapons systems emulators.

B. INTERMEDIATE LEVEL MAINTENANCE REPAIR CYCLE

Components requiring repair beyond the capability of the O-level are normally forwarded to the I-Level for induction into its repair process. These components, not being ready for use, are classified as Not Ready for Issue (non-RFI). Once inducted, they leave the I-Level only when they are Ready for Issue (RFI), or have been determined to be beyond the I-Level's capabilities. This latter occurrence is termed Beyond the Capability of Maintenance (BCM). A Maintenance Action Form (MAF) is generated for

each and every required repair. The MAF serves as the components sole documentation through the process. On it, the date that the component was put into the process, or inducted, and the date that the component left the process is noted. The difference between these two dates constitutes the Turn Around Time (TAT) or Mean Down Time (MDT) for that component within the I-Level organization. Mean Down Time includes not just the time actual repair work was performed, but also Administrative Delay Time (ADT) for processing of documentation, and time Awaiting Parts (AWP) also termed Logistics Delay Time (LDT).

Production control, a division within the I-Level, provides all coordination within the organization. It receives, routes, and tracks all MAFs through the I-Level. They are the central point of documentation. When the component MAF is received at Production Control a Received Date is assigned to the MAF. This is the date that the component was inducted at the I-Level. When the component is returned to the supply system in an RFI state, or classified as BCM, a Completion Date is assigned. These dates are the basis to measure MDT.

Work Centers (WC) perform the actual work on the non-RFI components. Within the I-Level, WCs are broken into functional areas, such as Airframes, Power Plants, and Avionics. The appropriate WC receives the MAF and the non-RFI component when Production Control establishes that the component will be needed for return to the system, and that the WC is capable of scheduling and accomplishing the job. Work Center maintenance personnel, upon receipt of the component, survey it assessing the physical and economic feasibility or repair, and proceed to diagnose the repair. The repair of sophisticated electrical equipment, such as modern avionics most often requires the use of ATE at this point. When diagnosed, repairs are accomplished, or required parts are ordered. If the component will be AWP for more than 24 hours, the MAF is annotated as such and the component is stored.

Automatic Test Equipment benches are computer controlled multi-function benches usually designed to interface with numerous different components. This adaptability is enabled through the use of software and universal interface connections. The advantages of using ATE is that it can accomplish a magnitude of system checks that would be physically infeasible for an individual to do otherwise. It can accomplish tasks faster, more accurately, and with less variation. Work centers performing avionics repair now rely almost exclusively on the use of ATE to diagnose faults, and to measure system performance. Most all avionics components repaired by the I-Level must pass an "end to end" check for proper performance without fault indication on the ATE prior to certification as RFI. The large extent of ATE use is economically necessitated. There now exists avionics equipment that can not feasibly be repaired without its use. ATE, like the components it is designed to repair does sometimes fail. Refocusing on MDT, if the ATE is in repair, components can not be repaired. Productivity of the I-Level Avionics work center is thus dependent on ATE availability, and reliability.

C. REPAIR CYCLE TIME IMPACT

The I-Level organization is in the unique position to have a great impact upon operational readiness. As stated, the O-Level has little ability to impact the inherent cycle time of the repair process, but benefits the most from its reduction. This is because the O-Level primarily deals with end unit components. When a failure occurs, they remove and replace the failed component with one from supply, if available. Otherwise they wait. The I-Level must feed the O-Level with RFI components at an adequate rate to maintain the operational availability, and thus readiness of the squadrons it supports.

Operational Availability is defined as the probability that a weapon system, when used under stated conditions in an operational environment, will operate satisfactorily

when needed. This is often equated with system readiness (Blanchard, 1992). The interchangeable terms, system readiness, or operational availability, A_O, are expressed as:

$$A_O = \frac{MTBM}{MTBM + MDT}$$

where:

- MTBM (Mean Time Between Maintenance) = $1/(\lambda+fpt)$ where λ is the failure rate and fpt is the preventative maintenance rate. This represents the mean time between all maintenance actions.

- MDT (mean down time) = M + LDT + ADT is total elapsed time required to repair and return a system to full operating status.

  where:

  - M (Mean Active Maintenance) = average elapsed time required to perform scheduled (preventive) and unscheduled (corrective) maintenance.

  - LDT (Logistics Delay Time) = maintenance downtime while awaiting parts, equipment, transportation, etc.

  - ADT (Administrative Delay Time) = maintenance delay due to administrative processing, personnel assignment priorities, etc.

The equation for A_O proves what the Logistics Strategic Plan (1995) states; "Time is the enemy of Logistics." Every hour of delayed response to the end user represents millions of dollars in inventories waiting to be moved, repaired, delivered, stowed, and used (OSD, 1995). Maintenance Down Time is a driver of readiness. If MDT is reduced, A_O is increased. Reducing any of MDT's three elements, M, LDT, or ADT accordingly has the needed effect. Cycle time reduction clearly increases the performance and flexibility of logistics needed by today's high technology operational forces.

Described by Mooney and Sanchez (1997), there are three scenarios of I-Level maintenance which dynamically demonstrate that reducing MDT is an effective strategy for improving spares availability and readiness. The third scenario, additionally demonstrates that the addition of spares alone over the long run can not improve A_O. The scenarios are:

- Scenario One: I-Level repair rate is equal to component failure rate.
- Scenario Two: I-Level repair rate is greater than component failure rate.
- Scenario Three: I-Level repair rate is less than component failure rate.

Utilizing the *Spreadsheet Decision Support Model for Aviation Logistics*, developed by Kang (1993), a graphic depiction is made of the impact MDT and RFI spares inventory has on A_O in each scenario. The model considers one critical repairable item of an aircraft at a time. Each time the readiness achieved as a function of spares and repair rate is computed. Comparison of the three scenarios shows the power MDT has on readiness.

The model's required inputs and provided outputs are as follows:

- Inputs: number of aircraft in system, component failure rate per aircraft, repair rate, and the number of spares in the system.
- Outputs: operational availability (A_O), number of aircraft grounded, average TAT for repair, and average quantity of work in process (WIP) for components.

Figure 1 is the graphical output of the model run under each scenario. Comparison of the three results illustrates that a reduction in MDT increases A_O at all levels of spares. Further, given a decrease in MDT, spares inventory required to maintain the same A_O decreases. Stated simply, <u>quicker TAT provides a choice to increase readiness, or to reduce spares inventory without degrading readiness</u>. Scenario Three in contrast shows the ill effects of decreasing repair productivity. Allowing the repair rate to fall below the

failure rate results in a steady state level of reduced readiness. Over the long-term, the resulting A_O can not be improved by the addition of spares. Throwing spares at the dilemma does provide short-term relief, but eventually they too will require repair resulting in the low steady state readiness depicted in the figure.

Without dispute, a reduction of the MDT improves weapon system's operational readiness, and allows selected reductions in logistics inventories to be made. Substantial savings can be obtained by reducing the TAT portion of MDT by even small amounts. This is at the center of the guiding principles and objectives of the Logistics Strategic Plan, and DoD logistics savings initiatives.

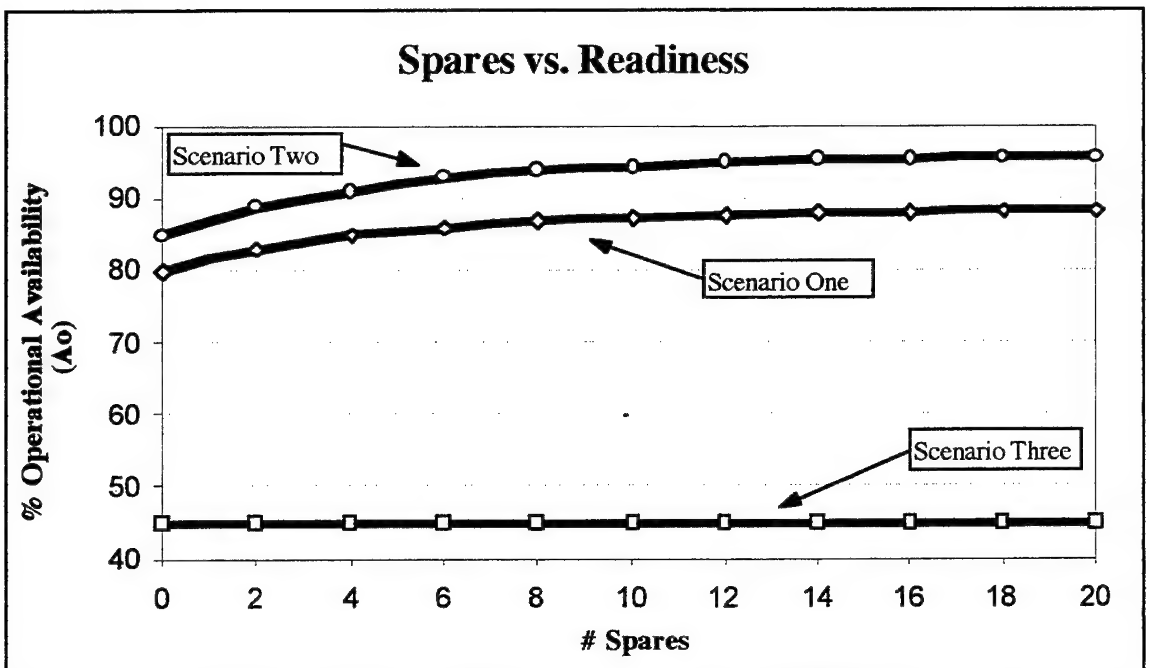

Figure 1. Impact of TAT on Operational Availability (A_O). (Mooney and Sanchez, 1997).

III. POWER QUALITY

There is virtually no piece of industrial production or repair equipment that does not depend on electricity in some form. Despite this very basic dependence, neither industry nor DoD has provided an encompassing standard for power quality. Incompatibility with the electrical environment is an increasing occurrence. *Business Week* (1991) reported that electrical power-related problems cost US businesses $26 billion a year in lost time and revenue according to an industry expert. The advent of the problem is two-fold. First is the sensitivity of the equipment being used in industrial and commercial facilities today. New equipment includes microprocessor-based controls and electronic devices that are sensitive to many types of disturbances less obvious than the traditionally recognized power interruption. Second is the fact that this sensitive equipment is interconnected in networks and automated processes. The whole system has become as sensitive as the most sensitive device within. (McGranaghan, 1997)

The reason that modern electronic equipment is more sensitive to electrical disturbances lies in its sophistication. These systems, because they include microprocessor controllers, utilize static power rectifiers. Static power rectifiers are known to create the disruptive phenomena known as a non-linear load. Figure 2 depicts a linear load and a non-linear load electrical sine wave. This equipment, causing non-linear loads, is disruptive to electrical systems, and because it utilizes microprocessor technology it is also susceptible to failure from "dirty" electricity. It is estimated that by the year 2000, sixty percent of all electricity will be passing through non-linear loads (Power Quality Assurance Online, 1996).

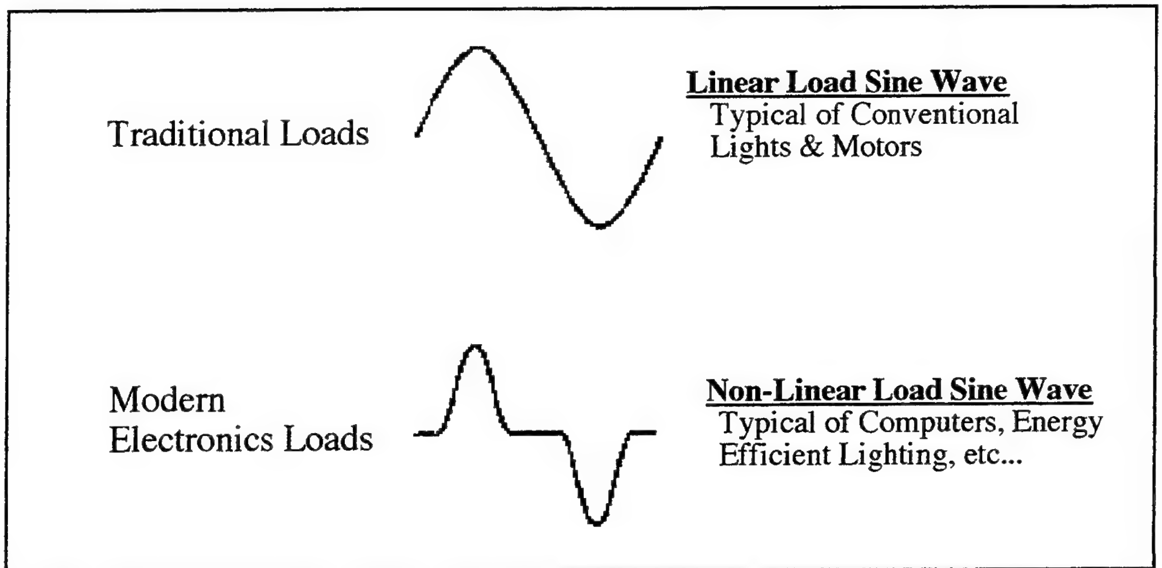

Figure 2. Linear Load vs. Non-Linear Load Sine Wave Comparison. (After Dranetz).

A. CAUSES OF POOR POWER QUALITY

A static power rectifier exists to conduct current from part of a cycle through multiple paths in order to convert alternating current (AC) to direct current (DC), and the reverse. This is called switch mode power. By its nature, switch mode power pulls electrical current in sharp, irregular or "non-linear" pulses compared with the smooth linear manner, called sinusoidal voltage, of traditional, less-sophisticated electronics. The undesired pulses created by the non-linear load are called harmonics. Non-linear loads contain substantial harmonics (multiples of 60 Hertz) which can react adversely with an electrical distribution system. Stated simply, as non-linear loads flow through a sites electrical system they cause voltage distortions. When delivered to equipment designed to accept a smooth linear flow of power these distortions can cause equipment malfunctions.

The proliferation of equipment that creates non-linear loads is great. Microprocessor controls, sensing equipment, computers, facsimile machines, laser printers, and electronic lighting are examples of items that utilize switch mode power

supplies and thus create non-linear loads. Unfortunately, the microprocessor controls present in these and other items are also highly sensitive to the presence of non-linear loads. The computer processors that are responsible for the greatest increases of control and efficiency in the production environment are partly responsible for the existence of non-linear loads, and ironically, also happen to be the most sensitive to damage from the resulting harmonic disturbance.

B. POWER QUALITY MANAGEMENT

Broadly defined, "quality power means having a consistent undistorted voltage available to all of your equipment (Power Quality Assurance Online, 1996)." The most often recognized portion of this concept, the "availability" of the power, is only a small part of actual power quality. Commonly practiced definitions fail to take into account several of the adverse effects of concentrated non-linear loads. These effects include:

- Voltage distortion within facilities
- Excessive neutral return currents
- High levels of neutral-to-ground voltage
- Overheated transformers
- Large magnetic fields emanating from transformers
- Decreased distribution capacity

From what quality power is, it can be summed that "bad" power is power that prevents equipment from working correctly, or causes damage to it (Power Quality Online, 1996). A central concept of power quality management is that the fault of unreliable equipment operation is often incorrectly assumed to be an equipment

malfunction when in fact the real cause is poor power quality. If the power supplied to the equipment was suitable in the first place the equipment might not have failed.

In the context of the equipment in the AIMD, switch mode power supplies exist in abundance. The pursuant distortions left uncorrected, or worse, aggravated by contributing factors of the facility, can damage equipment. In this manner, many perceived ATE system maintenance problems may actually be site power and grounding problems. ATE systems, which by nature are embedded networked computer systems, are dependent on having a quality power supply, and proper grounding circuitry. The following points taken from a Naval Aviation Engineering Service Unit (NAESU) Point Paper highlight the potential criticality of power quality to ATE performance: (McClelland, 1995).

- Every aspect of avionics facility electrical power and signal traffic is referenced to ground, measured to ground, and protected to ground. Ground, however, is never properly defined, measured, or maintained.

- Avionics power systems are installed and then ignored until catastrophic failure. These critical systems are not required to be periodically maintained.

- ATE equipment site requirements documents require grounds but do not adequately define the characteristics of a "good" ground.

- Avionics repair building ground systems are not periodically certified as are flight line ground pads yet all avionics ATE is referenced to this ground.

- AIMD Electrostatic Discharge (ESD) straps are connected to the site grounding system. When the grounds are faulty, so is the required ESD system.

- Ground is an impedance plan. It is never "zero" anything. Ground at NAS Lemoore (AIMD) Avionics has exhibited frequency components as high as 50 Mhz.

The traditional approach to power quality management has been a reactive one, investigating power quality problems only after they occur and all other possible causes

have been eliminated. Since the introduction of the first military ATE test bench in the mid-1970's, the VAST AN/USM-247, a frequently occurring scenario has been that of the technician faced with recurring ATE system failures repeatedly replacing a faulty item without performing any root cause analysis. The reason is that the majority of Naval avionics repair persons are simply not trained to consider site power or grounding problems as potential cause of ATE system failures. Further, in practice no proactive power quality management programs exist. The grounding circuits at Naval avionics repair sites where the ATE is located is not subject to preventive maintenance, and may degrade over time.

A proper power quality management program recognizes the existence of the power quality phenomena. It includes training to the users and maintainers of sophisticated electrical equipment, and incorporates routine preventative maintenance and inspection. These two simple steps, based in education, allow power quality sufficient for the application to be maintained, and for power quality induced malfunctions to be properly recognized as such and promptly corrected. An example of such success was reported by Fleet Technical Support Center, Pacific (FTSCPAC) in the USS Carl Vinson Pre-Deployment Electrical Power Survey and Inspection (PEPSI) report (1996). In an inspection to determine electrical power quality the ship was found to have few discrepancies. Likely of a cause and effect nature, it was also observed that ship's company electricians had received electrical distribution system training and been provided the use of a Power Line Analyzer. "The Power Line Analyzer ... is being put to good use." "Overall power quality aboard the USS Carl Vinson was excellent." (FTSCPAC, 1996)

The benefits from incorporating power quality management are site dependent. If a facility does not suffer from any of the phenomena of poor power quality, the introduction of a program will not result in immediate improvements. Industrial facilities,

like everything do change over time, however. Daily use, wear, facility modifications, and the addition of new equipment can all cause power quality problems to occur where they once did not. Preliminary evidence suggests that NAVAIR I-Level facilities do have wide spread power quality problems. Since NAVAIR ATE systems are standardized by hardware and software baselines, it can be assumed that independent user sites should see the same approximate levels of ATE reliability. This however is not currently seen in practice. Shore and ship I-Level facilities see a wide fluctuation of ATE reliability and maintenance costs. (McClelland, 1997). The likely input causing this process variance is power quality. The NAESU representative, Mr. Mike McClelland, at NAS Lemoore AIMD has provided technical support visits to several I-Level facilities ashore and afloat. His tech-assists routinely find similarly occurring problems to those found at NAS Lemoore.

C. BEST MANAGEMENT PRACTICES

Industry and DoD currently do have some established guidelines on power quality. These have their origins from electrical safety standards, and in the recent decade from practices proven beneficial for use by networked data equipment.

Power quality management should not be confused with the hardware used as its result. Best practices are not hardware based. They are processes and practices with economic underpinnings that have proven to result in the best outcomes. The elimination of damaging voltage spikes, ground loops, and system harmonics by the application of hardware solutions is the outcome of power quality management. An arbitrary application of power quality devices without considering the characteristics of the system and the devices may bring about a worse problem than the one they was intended to fix (Wilfong, 1996). Power quality management is an application of management and dictates a systems approach.

1. Current Industry Practices

Power quality management practices in the commercial sector are currently focused on defining the associated problems and methodology. Efforts include widespread monitoring of power quality, case studies of its impact, and the development of analytical tools for diagnosis. The Electric Power Research Institute (EPRI) recently sponsored a multi-year project to monitor power quality and distribution systems at 24 regions around the country. Some of the participating utilities extended their monitoring into customer's facilities to relate events on the distribution system to problems in the customer plants. This project typifies the state of the industry. Based in monitoring, and data gathering industry practices are evolving.

The Institute of Electrical and Electronics Engineers (IEEE) recently published a standard for power quality, *IEEE Recommended Practice for Monitoring Electrical Power Quality* (1159-1995). This is the most prominent industry action thus far. The IEEE standard states that "the purpose of the recommended practice is to direct users in the proper monitoring and data interpretation of electromagnetic phenomena that cause power quality problems." It defines the phenomena, and forms a consensus industry opinion about safe and acceptable methods for monitoring electrical power systems and interpreting the results.

Intertec International Inc., a power consulting firm, summarizes industry best practices with the following: "Testing and Maintenance are the key to keeping any sophisticated system operational. Planned maintenance has demonstrated its value in existing building systems... (Power Quality Assurance Online, 1996)."

2. Current Military Practices

Power quality management practices in the military currently are vague. Spread across at least five upper level directives*, DoD policy directs how electrical equipment is to be installed, but does not provide the same level of clarity on how it is to be maintained. *The Military Handbook for Grounding, Bonding, and Shielding for Electronic Equipment and Facilities* (MIL-HDBK-419A, 1987) only states that "initial and follow on maintenance inspection should be performed at regular intervals with chronological records of all test and observations maintained." Proper in intent, the instruction lacks direction in procedure. The NAMP (1998) assigns base Public Works (PW) to be responsible for the maintenance of I-Level and D-Level facilities. Individual PW departments, however, generally lack the experience, training, and equipment needed to carry out a power quality management program. Pockets of expertise do, however, exist within DoD. NAVAIR maintains a group of expert personnel trained to analyze ATE power discrepancies within its facilities called the Automatic Test Equipment / Electrical Power Interface Compatibility (ATE/EPIC) group. Inspections by the EPIC group though, are not routine, and are generally only done on request. An AIMD must first recognize their problems to be power quality related to know to request the proper help. Similiar to EPIC, Fleet Technical Support Center, Pacific maintains the Pre-Deployment Electrical Power Survey and Inspection (PEPSI) program. Established in 1988, the PEPSI program proactivly conducts inspections of ship board electrical power generator and distribution systems. Being highly sucessful in isolating complex power problems both the EPIC team and the PEPSI program have earned high degrees of

*Upper level directives applicable include; The Naval Occupational Safety and Health Program Manual (OPNAVINST 5100.23D), Space and Naval Warfare Systems Command Instruction for "Navy Shore Electronics Safety Precautions" (SPAWARINST 5100.9D), Military Handbook for Grounding, Bonding, and Shielding for Electronic Equipments and Facilities (MIL-HDBK-419A), The Naval Aviation Maintenance Program (OPNAVINST 4790.2G), and the National Electrical Safety Code (NFPA-70).

credibility. Programs such as these though, remain isolated examples of power quality management in DoD. They are often able to solve problems that have “baffled engineers and technicians for years” (FTSCPAC, 1997), but lack of funding and the shear magnitude of the number of organizations needing assistance limit their ability to solve everyone’s power quality problems. At the grass roots level, actual personnel using the equipment are commonly not accorded training or given guidance as to what power quality is, what is required, or what equipment failures precipitated by insufficient power quality appear as. DoD power quality management practices, despite some effective examples of programs are currently rooted in isolated individual personal efforts.

IV. METHODOLOGY OF COST-BENEFIT ANALYSIS

This chapter outlines the power quality management program actions taken by NAS Lemoore AIMD. It then explains the methodology taken to measure the costs and the benefits of these actions.

A. NAS LEMOORE AIMD HISTORY

Beginning in 1994, the AIMD at NAS Lemoore believed that the quality of the electrical power within their facility was insufficient for proper operation of their ATE. In response, they established a power quality management program within the AIMD. This action culminated with the creation of a local expert in power quality, Mr. Mike McClelland of NAESU, and the discovery that their facility did indeed have extensive electrical discrepancies requiring immediate correction. The cost-benefit analysis which follows recasts the decisions made by NAS Lemoore AIMD based upon their long-term historical outcomes actually experienced. The use here of an "after the fact" analysis will provide insight on alternatives for future direction.

Cost-benefit analysis of historical events allows the final value of actions taken to be measured by quantifying all of the historical costs and benefits of those actions. The sums quantified in this analysis are the costs to recognize and correct the AIMD's power discrepancies, the savings realized from subsequent reduction of ATE repairs, and the savings of subsequent productivity increases in processes utilizing the ATE. Scope of the analysis was limited to WC 650, and specifically to actions associated with the AN/USM-470(V)1 ATS. This work center is solely looked at because its repair processes are the most ATE intensive within the AIMD, and its power quality was the first to

receive attention within the Lemoore AIMD thereby making available the most data. Three ATS benches are located in WC 650 at AIMD NAS Lemoore.

1. Initial Power Quality Audit

In 1982, a building addition to the NAS Lemoore AIMD was completed for use by the F/A-18 avionics repair division, the 600 Division. Upon moving into the addition, an increase in the failure rates of all ATE was experienced. The root cause of the problem remained unidentified for two years until the new building's electrical ground network was inspected and diagnosed as faulty.

Then having only suspected facility discrepancies to exist, NAS Lemoore AIMD personnel established the beginnings of their power quality management program in response. Informal at first, personnel were educated on the characteristics and effects of power quality in complex distribution systems like those in their facility. In the later part of 1994, they conducted an electrical power distribution system self audit. In the course of the inspection they discovered seven Naval Occupational Safety and Health (NAVOSH) electrical safety hazards. Most of these hazards related directly to the grounding of the AN/USM-470(V)1 ATS in the avionics repair shop, WC 650. The most severe discrepancy was due to the fact that when the F/A-18 AIMD avionics wing addition was built the contractor never completed the electrical ground system. A section of the addition's perimeter ground cable had not been installed. Review of NAS Lemoore PW records revealed that no periodic ground system tests were ever conducted, the discrepancy being undetected until then. (McClelland, 1995)

In early January 1995, PW and AIMD personnel corrected the hazards found in the AIMD self audit. Public Works installed the missing section of ground cable. Public Works and AIMD personnel additionally rewired sections of the avionics wing's electrical distribution system. The avionics wing's interior grounding cables were re-routed and shortened. This lowered the impedance of the ground plane utilized by ATE in

WC 650. Missing neutral ground straps from both the 250 kilowatt 400 hertz generators, and the 60 hertz service transformer for the ATS were also installed. Internal to WC 650, Transient Voltage Surge Suppressers (TVSS) were installed which were provide by FTSCPAC under the auspices of the Non-Development Item (NDI) program.

Convinced then of the need to monitor the facility's electrical system, procedures within the AIMD were formalized to implement inspection requirements. Limited power quality monitoring and diagnosis equipment was also obtained, allowing in-house diagnosis of discrepancies, and monitoring of systems.

2. Winzler & Kelly Inspection

Winzler and Kelly Consulting Engineers were contracted to conduct a building ground survey for the AIMD avionics wing on 20-25 May 1996. Their survey reported that numerous discrepancies, although smaller in scope to those already found, remained. Corrective actions within the scope of AIMD personnel capabilities were completed immediately following the inspection.

3. Lyncole Technical Services Inspection

Lyncole Technical Services was contracted to assess the condition of the AIMD's ground system on 1-3 April 1997. Their survey specifically focused on the conditions of the grounding systems for ATE in terms of safety and electromagnetic compatibility for the proper operation of sensitive equipment. This survey found the facility's earth grounding counterpoise to be effective. However, several major grounding problems again were found internal to the facility. Included was the discovery of inappropriate neutral-ground bonds in panels and equipment. These bonds unintentionally placed amperage onto the facility's grounding system. This condition is commonly associated with equipment failures and "noisy" electronics operation.

B. COSTS TO PERFORM POWER QUALITY MANAGEMENT ACTIONS

The costs of the power management program at NAS Lemoore AIMD to date have been primarily internalized. The AIMD has mostly invested its own human capital to develop their program, paying outside resources only for repair assistance, and two annual inspections.

The investment of the AIMD's human capital, though paid to itself, was not without a cost however. Time spent investigating power quality phenomena, inspecting the facility, and reporting on its status could have been utilized doing other organizational tasks. These man-hours would have likely been spent repairing non-RFI components. Unfortunately, this time spent is undocumented. Its impact, if available, however, would have only been minimal. The fact that man-hours spent inspecting and repairing the facility were primarily during the same period that the return on investment resulted in negates the investment cost, or lost opportunity cost of these actions. The lost opportunity cost is accounted for because the work they did not accomplish was during the same time period of the analysis. The human capital investment of the AIMD is therefore accounted for by the cost of the lost productivity in the same period.

The initial cost of education for the AIMD's in-house expert, Mr. McClelland, also had an opportunity cost. It was not borne during the same period as the results were realized. Additionally, Mr. McClelland's role at the AIMD is as an engineering consultant, not an I-Level artisan, and is not accounted for by lost productivity. The cost of obtaining his education, again though internalized, can be estimated by equating it to the cost to attain the same knowledge external to the organization. Professional training courses exist which would provide equivalent knowledge. Power Consulting Education Training (PowerCET®) is a commercial firm offering nationwide power quality management training. They offer one and three day seminars on a number of topics in the

field. An appropriate syllabus to provide the equivalent initial training is provided in Table 1. The cost to complete that training, and therefore the assigned cost of Mr. McClelland's training is $2430. (PowerCET®, 1998). It is important to understand that this cost is not the benefit assigned to the training. The results of the cost-benefit analysis will bare its value out. It is the cost to efficiently obtain a resource, in this case knowledge.

Course Title		Duration	Cost
HM102:	Solving Harmonic Problems Using Power Analyzers	1 Day	$445
GND100:	Grounding for Equipment Performance	1 Day	$445
ESM100:	Equipment Sensitivity and Power Quality Measurement Techniques	1 Day	$445
PQ301:	Power Quality for the Year 2000	3 Day	$1095
		Total Cost:	$2430

Table 1. Equivalent Cost to Obtain Expert Knowledge.

Not accounted for yet is the reimbursable cost of PW's repair actions. Work requests annotating reimbursable costs of the PW actions were unavailable. Public Works involvement, however, was limited thereby lessening the impact of the absence of its cost data on the final analysis. This cost, if included, would have little effect on the outcome of overall value as the costs and savings found in this analysis are not of the same magnitude. The direction of outcome of the cost-benefit analysis is not sensitive to this lack of data.

The last items for inclusion are the costs of the Winzler & Kelley Inspection and the Lyncole Technical Services Inspection. Occurring in May 1996, the Winzler & Kelley Inspections cost the AIMD approximately $25,000 (Radder, 1998). The cost of the Lyncole Technical Services Inspection in April 1997 was $6,000 (Gill-Curry, 1997). These costs are included because of the affect they had on the AIMD overall. Although the majority of changes affecting WC 650 occurred in 1995 following the initial AIMD

self audit the systems approach of power quality management requires their inclusion when looking at periods of time which included them.

C. BENEFITS OF POWER QUALITY MANAGEMENT ACTIONS

Our analysis quantifies the two primary cost activities within the AIMD's 650 work center to arrive at the benefits resulting from their management of power quality. These two activities are the cost of maintaining the AN/USM-470(V)1 ATS utilized in WC 650, and the productivity of the repair processes utilizing the AN/USM-470(V)1 ATS in that work center. The benefit from reduction of the costs of repair of the ATE is measured by a comparison of the appropriate costs from before and after the application of power quality management. Process productivity changes are measured by comparing the MDT of sample WUCs in the populations from before and after changes were implemented. The desire is to construct a confidence interval for the difference between the mean, expressed as D_{bar}. This is done using a form of hypothesis testing known as the pairwise t test.

Given two dependent samples, D_{bar} is an unbiased estimator of μ_1-μ_2. Therefore D_{bar} may be used as a point estimator of the difference, and used to construct a confidence interval for that difference. Estimating the difference between two population means requires the completion of five steps. First, the population of difference scores must be determined to be from related samples and to be normally distributed. Second, the level of statistical confidence desired must be established. Third, random samples from the population must be obtained. Fourth, the mathematical intervals must be stated. Lastly, the resultant interval must be interpreted. (Glenberg, 1996) A detailed explanation of these five steps as performed in our research follows.

Pairwise sampling is used because it provides a more powerful means of statistical testing than independent sampling in this case. Given the same number of

observations, the pairwise sample procedure is more likely to result in the correct rejection of the null hypothesis than independent sampling. This is due to the reduced variability of the sampling distribution. The requirements for pairwise sampling is that the scores of the two samples are related to one another by a common characteristic. Our research utilizes a common application of pairwise sampling called "the before-after design." In this design, two measurements are obtained from each participant; one before some treatment, and one after the treatment. The treatment here is the management of power quality initiated in January, 1995.

1. Productivity Increases

The populations compared in this portion of the analysis are before treatment and after treatment dependent samples of WUCs repaired in WC 650 on the AN/USM-470(V)1 ATS. Appendix A provides a tabular listing of the population's WUCs. The outcome of this statistical process presents an interval within which the difference between the MDT of the before and after treatment population exits. This mean shift is the actual benefit derived from productivity increases brought about by the treatment. Appendix B includes a spreadsheet depiction of the five steps calculating the outcome interval. This methodology assumes that all other process inputs remained constant.

a) Satisfaction of Assumptions

Construction of a confidence interval using the pairwise t test requires two assumptions to be satisfied. First, the two samples must be dependent pairs. Use of the same WUCs across two periods ensured this relationship. The individual WUCs that make up the samples are independant and were choosen at random. This was achieved by randomly selecting 18 of 29 WUCs processed on the ATS. Two of the chosen WUCs were further eliminated because of insufficient size to provide a statistically significant component average. Second, D_{bar} must be derived from a normally distributed population. Our final analysis was based on 16 WUCs randomly chosen from 29 WUCs that form the

population of components repaired utilizing the AN/USM-470(V)1 ATS. The resulting group of D values was judged to be normally distributed. Appendix C is a histogram plot of the sample D values showing their normality of distribution. The robustness of the t statistic does provide latitude in this evaluation. The assumption of normality is usually considered satisfied for the purposes of the t statistic unless the population is grossly skewed. (Glenberg, 1996).

b) *Establishment of Confidence Level*

Confidence level is the probability that the null hypothesis is accepted when it is correct. This is defined mathematically as 1-α, where alpha (α) represents the probability of a Type I error. This is equal to the probability that the null hypothesis will be rejected when it is correct. Small values of α increase the probability that the calculated interval will include μ_1-μ_2, but result in correspondingly larger intervals to ensure inclusion of the true value. Our research utilized an α value of 5% (α=0.05) to yield a interval with high confidence, yet an informative range of value.

c) *Obtain Dependent Samples from the Population*

The AIMD 650 work center at NAS Lemoore repairs 42 WUCs. As stated, 29 or these utilize ATS in the repair process. Our research included 16 randomly selected WUCs from the period of 1 October 1993 to 12 December 1997. The division between populations for comparison was 1 January 1995 which approximated the date that power quality management was fully implemented at the AIMD. The populations were defined as 1 October 1993 to 31 December 1994, and 1 January 1995 to 12 December 1997. The data was compiled from NAS Lemoore's NALCOMIS AIMD Cost Accounting (NACA) database. The FY94.CHG, FY95.CHG, FY96.CHG, and CHNG.CHG files were stacked to create one database covering the full period of this analysis. The CHNG.CHG files

included 1997 and 1998 data through 12 December 1997. Database fields used to assemble the sample statistics were WC, WUC, ORDERDATE (requisition date), and COMPDATE (completed date).

All repairs which were administratively stopped, or determined to be Beyond Capability of Maintenance (BCM) were remove from the samples. These did not represent the statistic being measured, time to perform completed repairs. Additionally, entries which contained invalid data, such as a received date which preceded the completion date were also removed. An analysis of the sample groups variance using histogram and cumulative distribution frequency plots revealed skewness in the samples. The calculated D values were improperly biased by TATs greater than 30 days. Analysis of the AIMD work flow process, and interviews with AIMD personnel revealed that any TAT greater than 30 days was due to an AWP status (Brenneman, 1998). All data entries with a TAT greater than 30 days, accordingly, were also removed from the samples. This screening limited the effect that changes other than a shift in mean repair time (M) would have on the means comparison. This is the only filter in the analysis to remove the effect that process changes other than mean maintenance time may have had on the observed MDT shift.

d) Construct the Interval

Limit intervals of 1-α confidence were constructed utilizing the formula:

$$\text{Lower Limit} = D_{bar} - S_{Dbar} * t_{\alpha/2}$$

$$\text{Upper Limit} = D_{bar} + S_{Dbar} * t_{\alpha/2}$$

$$\text{Lower Limit} \leq \mu_1 - \mu_2 \leq \text{Upper Limit}$$

where:

$$D = X_1 - X_2$$

where X_1 and X_2 are the random variables that have mean μ_1 and μ_2 respectively.

$$D_{bar} = \frac{\Sigma D}{n_p}$$

$$S_D = \sqrt{\frac{\Sigma D^2 - (\Sigma D)^2/n_p}{n_p - 1}}$$

$$S_{Dbar} = \frac{S_D}{\sqrt{n_p}}$$

n_p = number of pairs of observations in the sample.

$t_{\alpha/2}$ = the value of the t statistic with n_p-1 degrees of freedom that has $\alpha/2$ of the distribution above it.

Quantities of components repaired, however, are not constant across WUCs. Appendix A shows the quantities of each WUC repaired during the period under analysis. Failing to appropriately weight the summation of the D and the D^2 values for the actual presence of each WUC in the system would have unfairly biased the resulting interval. Each D and D^2 value was thus counted in their summations on a one to one proportional basis with the quantity of that WUC repaired during the entire four year period. The result provides fair weighting to the D and D^2 values based directly on the total 3504 induction's among the 16 WUCs included in the samples. The total quantity of components repaired by the AIMD, not just those repaired in under 30 days, were applicable and included in this count.

e) *Interpret Outcome*

The resulting interval is interpreted as a 1-α probability that the calculated interval contains the actual difference between two population means, i.e., the MDT of the before and after treatment populations of this research. An alpha of 0.05 (α=0.05) provides only a 5% error probability that the calculated interval does not include the true value of μ_1- μ_2. This is the same as saying there is a 95% probability that the calculated interval contains the true difference between two population means.

Represented in units of a day, conversion of the process shift to a more meaningful unit of measure is desired. Conversion to monetary savings of reduced workload is accomplished by multiplying the appropriate cost of labor per unit by the process shift. It is not possible, however, to directly estimate the savings achievable from inventory reduction given this information. It was demonstrated in Chapter II that a reduction of MDT would allow definite savings to be achievable through reduced inventory requirements. The MDT shift calculated is an average per component for all components repaired without regard to WUC. The new procurement cost of these WUCs varies greatly making a reasonable estimate of inventory savings impracticable to make. It withstands logic though, as demonstrated in Chapter II, that the reduction in MDT allows some combination of an increase in operational availability or reduction of spares inventory to be realized. Benefits from increased operational availability and decreased inventory requirements will remain a demonstrated but unquantified benefit within this research.

The interval as calculated represents the overall reduction of MDT. Defined in Chapter II, MDT has three components, M, ADT, and LDT. For our purposes a measurement of the process shift of M alone would best represent the process improvements resulting from the application of power quality management, and therefore

would best measure this area of benefits derived. Non-availability of appropriate data, and analysis of the AIMD's processes, however, showed isolation of M to be beyond the scope of this research. Attempts were first made to ascertain measures of M, ADT, and LDT from the utilized data bases. The needed information, however, was not present in NACA databases prior to 1996. The next unsuccessful effort to isolate the process change of M vice MDT was to calculate the shift of MDT in WC 650 as already described, but to then subtract from it the MDT shift of a sample of WUCs from another work center that had not benefited from the implemented power quality management. It was thought that this would remove any process improvement that may have resulted from the streamlining of ADT or LDT. This methodology implied the assumption that all work centers would see equal improvements of ADT and LDT over the same period. The assumption false, it fails to acknowledge that each WUC's availability is established independently, therefore making any changes in the LDT associated with one WUC unrelated to another WUC. The methodology was further invalid because satisfactory separation between work centers could not be established. No one work center in the AIMD was completely sheltered from the effects of the application of power quality management. The use of sensitive electronic equipment, including other types of ATE, is prolific throughout the AIMD. Another separate reason for the failure of this attempted step was that no single work center's shift of MDT could proxy for an AIMD wide change of just ADT and LDT. Each work center's processes are too dynamic possibly having been changed by other unrelated process improvements.

2. ATE Maintenance Savings

More easily isolated, comparison of the maintenance costs of the AN/USM-470(V)1 ATS from before and after the application of power quality management is accomplished by comparing the sums of all ATS maintenance costs during the two periods. The costs already exist on a common frame of comparison, the ATS benches

being in an active powered state 365 days per year with little exception. Mechanical wear out has little effect on their reliability. These ATS maintenance costs include the cost of I-Level repaired components for the ATS, and the cost of ATS components labeled BCM and sent to the Depot. Where periods differed in time span, the totals were averaged to represent the same unit of time. This averaging is from here on out refereed to as being "normalized to represent a 12 month period."

The ATS maintenance cost data used is from 1 October 1993 to 12 December 1997. Again, the division between periods of comparison was 1 January 1995, approximating the date that power quality management was fully implemented at the AIMD. Data was queried from the NAS Lemoore maintained NACA database files FY94.CHG, FY95.CHG, FY96.CHG, and CHNG.CHG databases. The three test benches were identified by their type equipment code, GVAN. Database fields used to assemble the sample statistics were WC, TEC (Type Equipment Code), ORDERDATE (requisition date), COMPDATE (completed date), and PRICE (numeric conversion of extended price data).

3. Quality of Output

The quality of the output produced by WC 650, the avionics components repaired, was not included for analysis in this research. If output quality did change as a result of the implementation of power quality management this change too is a cost or benefit. An improvement in the quality is a benefit, degradation of quality a cost. Two metrics which measure the output quality are the supported squadrons' material condition "Y" code rates, and the MTBFs of the components repaired.

"Y" code is the material condition applied to RFI components received by the squadron that prove to be faulty upon receipt. Analysis of this output characteristic was determined to be beyond the scope of the research due to the inherent difficulty of obtaining the required data. Initial framing of analysis, however, saw that study of the

"Y" code rates of the squadrons receiving components from the AIMD would show if a change had occurred in the accuracy of the ATE to properly diagnosis components as RFI or non-RFI. "Y" coded components either become faulty in storage or transit, or are passed on by the AIMD as RFI when faults still exist within them. Breakage in transit and storage is guarded against minimizing its occurrence. The later reason is a result of the ATE's sensitivity to a component's faults. It is conceivable that the quality of the power supplied to ATE may have an effect on the benches' probability of passing on bad components, also referred to as its alpha (α) value. The opposite also being conceivable, the benches beta (β), or probability that the bench classifies good components as faulty, may too be affected. A shift in the process α is measurable by the "Y" code rate at supported squadrons. A shift in the β would remain invisible, however, the components being scrapped, or sent to the depot as BCM, making the discovery that the component was really good impracticable.

More visible to the Naval maintenance system, and providing and excellent measure of output quality is the MTBF of repaired components. Comparisons of MTBFs over time, however, do not strictly isolate the affect on the process brought about by the management of power quality. Individual components are subject to changes of central tendencies due to age, and modifications. The measurement and comparison of components between periods would have to take these externalities into account. The addition of component MTBF comparison to this cost-benefit analysis was also not possible due to time constraints, and again the inherent difficulty to obtain data.

D. DEFAULT PARAMETERS

Where required the default parameter data in Table 2 was used in calculations. These parameters are taken from the LORA Default Data Guide (1995). This data is taken from higher directives or forecasted as applicable by NAVAIRSYSCOM and promulgated for use in NAVAIRSYSCOM analysis. The parameters are intended to provide proper and best estimates.

LORA Default Data Guide - March 1995	
Discount Rate	7%
Labor Rate-Land Base Military (Avionics)	$22.33/hr.
Work Week-Land Based Military	32 hrs./wk.

Table 2. Default Data used for Savings Calculations.

V. COST-BENEFIT ANALYSIS RESULTS

This chapter presents the calculated costs and benefits of power quality management program actions taken by NAS Lemoore AIMD. Further, the significance of these differences are explained.

A. OVERVIEW

Naval aviation readiness is directly linked to the availability of parts needed for repair of aircraft at the operational unit. In turn, the ability of the I-Level to materially support the O-Level in a timely manner ultimately determines readiness. In this building block fashion, battles are won with tactics, but wars are won with logistics.

The purpose for quantifying the benefits of the power quality management program at NAS Lemoore is to improve readiness and to produce monetary savings by increasing awareness of process enhancements which improve cycle time and reduce inventory investment. The management of power quality in processes dependent on the proper functioning and operation of sensitive electronic equipment is shown here to reduce the failure rate of the equipment, and to improve the performance of the equipment. By quantifying the results of one application of power quality management the wide potential for savings can been seen, and the magnitude understood.

The first part of this chapter summarizes the costs borne by NAS Lemoore AIMD in managing their power quality through an initially informal and later more formal program. The second part of this chapter summarizes the benefits of the program developed and carried out by the AIMD. The determination of a monetary value of

savings is the primary tool to display the level of success achieved. Other benefits, not of a quantifiable monetary value are also brought forward and explained.

B. COSTS

The costs to the AIMD to manage their power quality have been both internal and external. Internal costs have primarily been the opportunity cost of AIMD personnel's time to inspect for, identify, and repair discrepancies within its facility. These costs are accounted for in measures of change of productivity. External costs have been the costs to acquire expert knowledge, and the cost to out-source inspections. Defined in Chapter IV, total external costs and their present values as of 1 January 1998 are listed in Table 3.

Item	Date	Cost	Present Value Cost (1/98)
NAESU Rep Training	January 1995	$ 2,430	$ 2,794.03
Public Works Repair Assistance	January 1995	*Unquantified*	*Unquantified*
Winzler & Kelley Inspection	May 1996	$25,000	$28,084.10
Lyncole Inspection	April 1997	$ 6,000	$ 6,322.45
		Total Present Value Cost:	$37,200.58

Table 3. External Costs of Power Quality Management Program.

C. BENEFITS

Two primary streams of benefits resulted from the implementation of the power quality management program at the AIMD. The first and most easily observed was the immediate decrease of the annual cost to repair the three AN/USM-470(V)1 ATS benches in WC 650. The second, less obvious benefit, was a reduction in the average TAT of components repaired on the ATS benches.

1. ATE Maintenance Savings

AIMD Lemoore began managing their power quality because of the high ATE failure rates they were experiencing. Comparison of the ATS failure rate before and after 1 January 1995 displays the extent of the problem that had existed, and the shocking success they achieved in reducing it. In the first year of the program, the failure rate of the three ATS benches in WC 650 was reduced to half that of the prior year's rate. Correspondingly, bench repair costs decreased 45%. Table 4 is the cost to repair the three ATS benches and the number of repairs made by year.

	Pre Treatment	*Post Treatment*			*Avg. Post*
Source	1994 *	1995	1996	1997 *	Avg. per yr. 1995-1997*
# of ATS Repairs	184	72	72	20	55
Total Cost of ATS Repairs	$211,842	$116,949	$110,701	$55,313	$94,321
Saving from Baseline Year	$0	$94,893	$101,141	$156,529	$117,521
Present Value of Savings (1/98)	$0	$108,643	$108,221	$156,529	

* 1994 and 1997 Quantities are Normalized to represent 12 months.

Table 4. ATS Repairs and Repair Costs.

The savings from the decrease in maintenance costs alone economically justify the actions taken by the AIMD. At the end of 1995, the AIMD enjoyed an average return on investment of only nine days. This savings was directly and immediately realized. The alignment of the savings with the organization responsible for the actions which brought it about is important to note. If an organization is able to realize a savings themselves, they are more apt to act and succeed. Savings additionally were realized quickly, still in the time frame near that of their efforts made. These points demonstrate the practicality with which power quality management programs can be implemented on a wide spread basis. As experienced at AIMD Lemoore, those responsible for the program already have

a vested interest to succeed. Their immediate benefit is savings of their own maintenance budget.

Sensitivity analysis of the reductions in repair costs confirms that savings are not dependent on the number of components processed during the period. The assumption made is that ATS bench failure are distributed based on the continuous operation of the bench, vice its active usage rate. This is normal for electronic equipment. Comparison in Table 5 of the total quantity of components repaired using the three ATS benches (process output) to the number of repairs to the ATS benches (a process input) show no relationship between the two sets of numbers. The data is further developed into an output to input ratio similar to Mean Time Between Failures (MTBF) which is expressed:

$$\mathrm{MTBF} = \frac{1}{\left(\frac{\#\ \mathrm{Failures}}{\mathrm{Total\ Time}}\right)}$$

Instead of using time, however, the ratio developed uses quantity of output, and is termed Mean Output Between Failures (MOBF) expressed as:

$$\mathrm{MOBF} = \frac{1}{\left(\frac{\#\ \mathrm{Failures}}{\mathrm{Total\ Output}}\right)}$$

	Pre Treatment	*Post Treatment*		
Year:	1994 *	1995	1996	1997 *
Total Number of Components Repaired	1016	1023	1209	1047
Total Number of ATS Repairs	184	72	72	20
MOBF	5.52	14.21	16.79	52.35

* 1994 and 1997 Quantities are Normalized to represent 12 months.

Table 5. Insensitivity of ATS Repairs to Process Output.

Marked changes are seen to occur in 1995, and again in 1997. These are attributable to the success of the inspections conducted in January 1995, and April 1997, and that their findings applied directly to WC 650, the subject of this analysis. The May 1996 inspection did not yield findings closely related to WC 650 (McClelland, 1998). An AIMD wide analysis of costs and outputs would likely show further benefits in other work centers from it.

2. Productivity Increases

The less obvious area of savings experienced, but of potentially greater long term value to DoD, is the savings achieved by the AIMD in reducing their cycle time. Any reduction of cycle time produces gains in operational readiness, and allows pipeline inventory reductions to be accomplished. Further, when I-Level work is accomplished more efficiently the system's surge capacity is greater; the AIMD being better able to support squadrons during periods of rapidly increased operations. Yet another unquantified, but logical benefit of greater I-Level efficiency is enhancement of individual's quality of life. If the AIMD can properly support squadrons in less time, more time is made available for unit morale building events, and individual liberty. While this may or may not have occurred, the opportunity likely existed. Quality of life enhancements are known to increase retention of sailors and marines, and is a stated objective of the Logistics Strategic Plan (1995).

Parametric analysis of the processes in WC 650 as displayed in Appendix B shows that the mean TAT of components repaired utilizing ATS <u>decreased between 0.381 and 0.468 days</u> after 1994. This equates to a reduction in MDT of between 9 hours 8 minutes and 11 hours 14 minutes. The AIMD currently operates around the clock five days per week utilizing three 8 hour shifts per work day. As such, no time is lost in a conversion from days to hours and minutes. The AIMD from 1995 through 1997 annually repaired in excess of 1000 components using the ATS benches. The average reduction in

TAT per component interval, 10 hours 11.28 minutes, multiplied by the total number of components repaired utilizing ATS yielded over a 10,000 hour annual savings from the process baseline measured from 1994. This equates to having saved over $230,000 per year, the cost otherwise required to employ six additional sailors that would have been required to accomplish the same annual output under the 1994 baseline process. Table 6 displays the savings per year below the baseline. Table 7 is the present value of these savings as of 1 January 1998. The present value calculations conservatively assume an end of the year accumulation of savings.

Year	Avg. TAT Reduction	Qty Components Repaired on ATS	Cost/Hr. of Labor	Annual Savings of Labor
1994 *	0 hrs. 0 mins.	1016	$22.33/hr.	$0 (baseline year)
1995	10 hrs. 11.28 mins.	1023	$22.33/hr.	$232,730.49
1996	10 hrs. 11.28 mins.	1209	$22.33/hr.	$275,045.13
1997 *	10 hrs. 11.28 mins.	1047	$22.33/hr.	$238,190.45

* 1994 and 1997 Quantities are Normalized to represent 12 months.

Table 6. Annual Savings of Productivity Increase.

Year	Annual Savings	Present Value
1994	$0 (baseline year)	$0 (baseline year)
1995	$232,730.49	$266,453.14
1996	$275,045.13	$294,298.29
1997	$238.190.45	$238,190.45
	Total Present Value:	$798,941.88

Table 7. Present Value of Savings from Productivity Increases.

Linking the reduction of TAT to power quality improvements, and not other process changes which could have occurred also lowering MDT is the fact that prior to 1995, when ATE failure rates were at their peak, AIMD's avionics personnel frequently ran excess checks of components. They did this to ensure product quality because they

greatly lacked confidence in the ability of their ATE to perform correctly. Prior to 1995, the ATS benches would typically fail during one out of every 5 $^1/_2$ repairs. According to McClelland (1998), this caused sailors to lack faith in a benches' report. A diagnosis of RFI was often not trusted. Avionics personnel routinely repeated ATE bench check tests multiple times to gain confidence in the reported outcome. These added test cycles slowed component repair TAT. Increased reliability of the ATS benches has reinstilled the confidence of the I-Level avionics personnel in its ability to check out a component accurately, and correctly the first time. Component tests now being run only once streamlines TAT. Increases in bench reliability also eliminated a repetition of work which would occur when a bench failed mid-test. Proper repair and testing of components requires "end to end" test runs on the ATE. If the process is interrupted due to a bench failure, it must be restarted at the beginning once the bench is fixed. All of the time spent to that point is wasted. Reduction of bench failures decreases the frequency of this occurrence. With management of power quality, the bench is up more often, allowing repairs to be completed more efficiently. These streamlinings of the process directly tie some degree if not all of the reduction of MDT to power quality management. It should be restated, however, that other components which contribute to MDT are assumed not to have changed in the methodology taken in this analysis. Any reductions achieved in ADT or LDT during the same periods would correspondingly reduce the stated productivity savings from power quality management.

D. TOTAL PRESENT VALUE

Table 8 presents the calculated benefit to date of the power quality management program in WC 650 at the NAS Lemoore AIMD. This benefit is calculated over the three year period the program has been in place at NAS Lemoore, and is summed to represent the total benefit received during this period. Viewing of the entire period vice a year by

year analysis is appropriate at this early stage of the program's development to achieve a more stabilized understanding of the actual benefits gained. The program implemented at NAS Lemoore required time to be phased in, and not all effects were immediately realized. Annual savings from the base year are expected to continue, however, increases of the savings are expected to display marginal rates of growth. Key events when savings growths will again be made possible will occur whenever status que within the facility is disturbed. These events will include the installation of new equipment, modifications to facility electrical systems, failures of the facility electrical system due to age, etc.

Category	Description	Monetary Value
Total Costs as of 1/98	Costs:	<$37,201>
Total Benefits as of 1/98	Savings from Repairs:	$373,393
	Savings from Productivity:	$798,942
	Savings from Operational Readiness:	*Unquantified*
	Savings from Quality of Life Enhancements:	*Unquantified*
Total Present Value of Power Quality Management 1/94 - 12/97:		**$1,135,134**

Table 8. Three Year Total Present Value of Power Quality Management Program at NAS Lemoore AIMD, WC 650

This accounting shows definite success on AIMD Lemoore's part. The implementation of power quality management practices in 1995 was and remains a success with savings ranging from $336,192 to $1,135,134 depending on the extent to which the assumptions made did actually occur.* At either extreme, its application at

*The primary assumption required for the full extent of the savings to exist is that no reduction of ADT or LDT occurred in the process of WC 650 at NAS Lemoore AIMD during the period of 1995 through 1997. Given the emphasis of logistics reform during

NAS Lemoore has saved needed DoD money, has benefited its sailors who in turn then continue to contribute to the Navy, and has increased the day in day out operational readiness of Naval aviation. The final true worth of all benefits can never completely be measured. NAS Lemoore AIMD's motto is "Quality Parts Out the Door." They have and continue to accomplished this and more. Through the innovative implementation of new ideas and up and coming practices, NAS Lemoore AIMD positively contributes to keeping the United States a strong naval force able to project power worldwide to execute national policy.

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this period some reduction of LDT likely did occur, appropriately lessening the confidence of having saved the full amount calculated.

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The focus of this research has been on the reduction of both direct maintenance costs, and repair cycle time in ATE intensive repair facilities by using power quality management to identify facility improvements which enhance the repair process. Chapter V detailed a $1,135,134 savings and other benefits yielded in the avionics repair shop at AIMD NAS Lemoore through the application of a power quality management program. The costs and benefits of the implementation of the program were measured by measuring the process inputs and outputs before and after power quality management was applied. The difference was identified as the program's value.

Improved operational readiness is the ultimate goal of all material repair activities. Simultaneously, this is accompanied by a responsibility to preserve DoD's limited resources. Any incremental savings which can be realized through cost reduction, process streamlining, or inventory reduction can be applied to modernizing and procuring weapons systems. All savings opportunities accordingly must be pursued. Commercial industry too has recently recognized the relationship between power quality and system performance. As detailed in Chapter III, industry's treatment of power quality is evolving as they are better recognizing the need to manage it. Like industry, DoD must evolve its treatment of this subject in recognition of the achievable improvements. The commercial practices and policies of industry should be applied.

Many opportunities outside of the avionics repair facility exist to benefit system performance by ensuring power quality. The AN/USM-470(V)1 ATS is but one type of

ATE that can benefit from the management of power input quality. Similarly, automatic test equipment is but one type of sensitive electronic equipment that can benefit as well. We have focused our analysis on the savings achieved in an aviation I-Level setting. The escalating use of "high technology weaponry" is continuing to grow the list of activities and processes which also utilize sensitive electronic equipment and could therefore benefit as well. The concepts of savings, process streamlining, and inventory reduction apply equally across organizations both inside and outside of Naval aviation. The end result always remaining the needed conservation of DoD's limited resources for other use.

B. CONCLUSIONS AND RECOMMENDATIONS

- **Conclusion 1** - Power Quality Management Programs as a process management tool can identify areas of substantial cost savings.
  - **Recommendation** - Military activities using sensitive electrical equipment should become familiar with power quality concepts, and explore the need to adapt power quality management practices. When adopted, practices should include the education of equipment operators and maintainers, and requirements and funding for inspection of electrical distribution systems supplying power to sensitive electrical equipment. Adopted inspections should be on a recurring basis and additionally following major facility modification, or equipment installation. Training and education is key in the management process. The appropriate major systems commands should provide for the needed training, and establish expert inspection teams, or provide for the outsourcing of inspection teams to conduct inspections as required.

- **Conclusion 2 -** Current industry guidance for power quality management is more comprehensive, and more clearly stated than DoD guidance.

  - **Recommendation -** Department of Defense major systems commands and cognizant authorities of sensitive electrical equipment should examine and adopt as appropriate industry standards and guidance on power quality. The *IEEE Recommended Practice for Monitoring Electrical Power Quality* (IEEE Std 1159-1995) and *IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment* (IEEE Std 1100-1992) should be reviewed at a minimum.

- **Conclusion 3 -** Commercial industry definition, advances, and application of best practices in power quality management can provide useful examples of where power quality management may be beneficial, and how it may best be managed.

  - **Recommendation -** Military organizations using sensitive electrical equipment should search industry for users of similar equipment and compare power quality management practices and process outcomes. Metrics of comparison should include equipment failure rates, causes of equipment failures, equipment operating efficiencies, and logistical burdens to support the equipment. Successful applications of power quality management can be used as "troubleshooting" guides to solve occurrences of similar power quality phenomena suffered in DoD facilities.

C. AREAS FOR FURTHER RESEARCH

This research did not compare the output of the process at NAS Lemoore to that of other like organizations to see if repaired components differed in quality. Further research comparing the MTBF of NAS Lemoore AIMD's output to the MTBF of components from the remaining population of Naval aviation I-Level organizations would benefit this field of research.

APPENDIX A. POPULATION COMPOSITION

The WUCs which constitute the population of components repaired in WC 650 of the NAS Lemoore AIMD are displayed here with the frequency of their occurrence. The total quantity and the average annual quantity (normalized quantity) of each WUC in the population are presented separately.

WUCs Choosen as Samples of Population

Work Unit Code (WUC)	Total Qty (10/93-11/97)	1994	1995	1996	Through Nov 97
4115700	308	76	72	58	102
4431420	373	68	98	135	72
5111C00	152	63	36	41	12
57D9500	231	51	52	79	49
57D9600	36	13	10	8	5
5838400	44	10	5	10	19
64X1100	119	28	30	36	25
64X1G00	406	79	83	147	97
67X2200	477	158	98	141	80
67X2300	428	107	96	131	94
74D7200	83	39	2	28	14
74D7300	47	15	19	4	9
74D9400	440	109	116	84	131
74D9800	114	34	26	18	36
74D9A00	208	54	49	52	53
76X4500	38	8	2	23	5
Total Qtys:	3504	912	794	995	803

WUCs in Population Not Choosen as Samples

Work Unit Code (WUC)	Total Qty (10/93-11/97)	1994	1995	1996	Through Nov 97
24A8300	54	53	0	1	0
4911100	9	7	1	1	0
4911230	6	0	0	1	5
4942100	117	49	27	26	15
73M1820	5	0	5	0	0
73M1840	0	0	0	0	0
73X3220	138	38	44	29	27
7468120	153	46	39	33	35
7468140	296	94	73	76	53
7468150	118	36	17	46	19
7468340	62	35	23	1	3
74D9500	0	0	0	0	0
74D9600	0	0	0	0	0
Total Qtys:	958	358	229	214	157

Total Qty in Population of Components Repaired by WC 650

	Total Qty (10/93-11/97)	1994	1995	1996	Through Nov 97
Total Qtys:	4462	1270	1023	1209	960

WUCs Choosen as Samples of Population

Work Unit Code (WUC)	Total Qty * (1994-1997)	1994 *	1995	1996	1997 *
4115700	302	61	72	58	111
4431420	366	54	98	135	79
5111C00	140	50	36	41	13
57D9500	225	41	52	79	53
57D9600	34	10	10	8	5
5838400	44	8	5	10	21
64X1100	116	22	30	36	27
64X1G00	399	63	83	147	106
67X2200	453	126	98	141	87
67X2300	415	86	96	131	103
74D7200	76	31	2	28	15
74D7300	45	12	19	4	10
74D9400	430	87	116	84	143
74D9800	110	27	26	18	39
74D9A00	202	43	49	52	58
76X4500	37	6	2	23	5
Total Qtys:	3395	730	794	995	876

* 1994 & 1997 Totals are Normalized to represent 12 Months.

WUCs in Population Not Choosen for Samples

Work Unit Code (WUC)	Total Qty * (1994-1997)	1994 *	1995	1996	1997 *
24A8300	43	42	0	1	0
4911100	8	6	1	1	0
4911230	6	0	0	1	5.4545
4942100	109	39	27	26	16.364
73M1820	5	0	5	0	0
73M1840	0	0	0	0	0
73X3220	133	30	44	29	29.455
7468120	147	37	39	33	38.182
7468140	282	75	73	76	57.818
7468150	113	29	17	46	20.727
7468340	55	28	23	1	3.2727
74D9500	0	0	0	0	0
74D9600	0	0	0	0	0
Total Qtys:	901	286	229	214	171

* 1994 & 1997 Totals are Normalized to represent 12 Months.

Total Qty in Population of Components Repaired by WC 650

	Total Qty * (1994-1997)	1994 *	1995	1996	1997 *
Total Qtys:	4295	1016	1023	1209	1047

* 1994 & 1997 Totals are Normalized to represent 12 Months.

APPENDIX B. TAT MEAN SHIFT

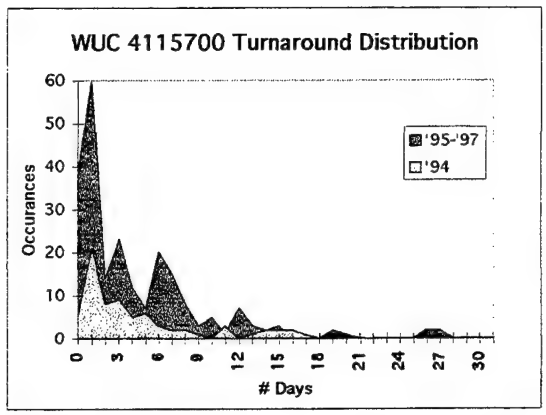
A example printout of the data source used, statistics of the 16 WUCs selected in the analysis sample, and a spreadsheet calculations of the pairwise t statistic comparison is displayed here.

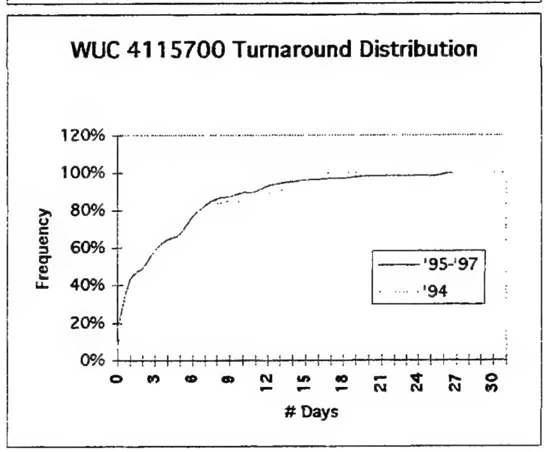
	A	B	C	D	E	F	G	H
1	WC	DDSN	WUC	QTY	NIIN	NOMEN	ORDERDATE	TDATE
2	650	3272GF05	4115700	1	011506560	CONTROL BOX P	93272	93274
3	650	3286GL47	4115700	1	011506560	CONTROL BOX P	93286	93286
4	650	3300GT37	4115700	1	011506560	CONTROL BOX P	93300	93301
5	650	3307GT37	4115700	1	011506560	CONTROL BOX P	93307	93308
6	650	3321GP50	4115700	1	011506560	CONTROL BOX P	93321	93323
7	650	3323GB09	4115700	1	011506560	CONTROL BOX P	93323	93325
8	650	3335GV20	4115700	1	011506560	CONTROL BOX P	93335	93336
9	650	3348GL56	4115700	1	011506560	CONTROL BOX P	93348	93349
10	650	3354GL74	4115700	1	011506560	CONTROL BOX P	93354	93356
11	650	4005GM13	4115700	1	011506560	PA005 CONTROL	94005	94007
12	650	4010GL49	4115700	1	011506560	PA005 CONTROL	94010	94011
13	650	4012GL83	4115700	1	011506560	PA005 CONTROL	94012	94013
14	650	4014GL08	4115700	1	011506560	PA005 CONTROL	94014	94017
15	650	4019EH49	4115700	1	011506560	PA005 CONTROL	94019	94023
16	650	4025GT68	4115700	1	011506560	PA005 CONTROL	94025	94027
17	650	4039GT43	4115700	1	011506560	PA005 CONTROL	94039	94039
18	650	4045GT35	4115700	1	011506560	PA005 CONTROL	94045	94046
19	650	4045GT38	4115700	1	011506560	PA005 CONTROL	94045	94046
20	650	4046GT45	4115700	1	011506560	PA005 CONTROL	94046	94046
21	650	4046GT46	4115700	1	011506560	PA005 CONTROL	94046	94046
22	650	4046GE09	4115700	1	011506560	PA005 CONTROL	94046	94048
23	650	4049GT21	4115700	1	011506560	PA005 CONTROL	94049	94049
24	650	3279GP76	4115700	1	011506560	CONTROL BOX P	93279	94057
25	650	4059G122	4115700	1	011506560	PA005 CONTROL	RP&RT	94063
26	650	4066GQ31	4115700	1	011506560	PA005 CONTROL	RP&RT	94069
27	650	4075GK57	4115700	1	011506560	PA005 CONTROL	94075	94076
28	650	4075DT20	4115700	1	011161588	CIRUIT CARD	94075	94080
29	650	4081GL78	4115700	1	011506560	PA005 CONTROL	RP&RT	94088
30	650	4088GP54	4115700	1	011506560	PA005 CONTROL	94088	94090
31	650	4094GV39	4115700	1	011506560	PA005 CONTROL	94094	94095
32	650	40964050	4115700	1	011506560	PA005 CONTROL	RP&RT	94102
33	650	4109GF52	4115700	1	011506560	PA005 CONTROL	94109	94110
34	650	4109GP77	4115700	1	011506560	PA005 CONTROL	94109	94111
35	650	4108GT83	4115700	1	011506560	PA005 CONTROL	94108	94111
36	650	4110GF60	4115700	1	011506560	PA005 CONTROL	94110	94111
37	650	4110GF63	4115700	1	011506560	PA005 CONTROL	94110	94111
38	650	4112GT28	4115700	1	011506560	PA005 CONTROL	94112	94115
39	650	4112GF01	4115700	1	011506560	PA005 CONTROL	94112	94116
40	650	41024052	4115700	1	011506560	PA005 CONTROL	RP&RT	94116
41	650	4123GT65	4115700	1	011506560	PA005 CONTROL	94123	94124
42	650	4130GL16	4115700	1	011506560	PA005 CONTROL	94130	94131
43	650	4131GP43	4115700	1	011506560	PA005 CONTROL	94131	94136
44	650	4133GT14	4115700	1	011506560	PA005 CONTROL	94133	94136
45	650	41234052	4115700	1	011506560	PA005 CONTROL	RP&RT	94136
46	650	4145GL26	4115700	1	011506560	PA005 CONTROL	94145	94146
47	650	4152GT34	4115700	1	011506560	PA005 CONTROL	94152	94153
48	650	4146DT02	4115700	1	011161583	CIRCUIT CAR	94146	94157
49	650	4156GF07	4115700	1	011506560	PA005 CONTROL	94156	94159
50	650	4144GL78	4115700	1	011506560	PA005 CONTROL	RP&RT	94160

WC:	650	*Data Under 30 Days ONLY*
WUC:	4115700	F-18 A/C/D ACS TEMP/FLOW ELECTRICAL CONTROL
		BCM DELETED

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days	StdDev Days
1994	73	4.438	0	17	17	4.589
1995	71	5.507	0	26	26	4.763
1996	57	4.491	0	27	27	6.150
1997	101	3.436	0	26	26	4.607
All Years:	302	4.364	0	27	27	5.000
95-97:	229	4.341	0	27	27	5.134

	Oct '93-'94		'95-'97	
Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	5	6.85%	38	16.59%
1	21	35.62%	60	42.79%
2	8	46.58%	14	48.91%
3	9	58.90%	23	58.95%
4	5	65.75%	12	64.19%
5	6	73.97%	7	67.25%
6	3	78.08%	20	75.98%
7	2	80.82%	15	82.53%
8	2	83.56%	8	86.03%
9	1	84.93%	3	87.34%
10	0	84.93%	5	89.52%
11	3	89.04%	1	89.96%
12	0	89.04%	7	93.01%
13	1	90.41%	3	94.32%
14	2	93.15%	2	95.20%
15	2	95.89%	3	96.51%
16	2	98.63%	0	96.51%
17	1	100.00%	1	96.94%
18	0	100.00%	0	96.94%
19	0	100.00%	2	97.82%
20	0	100.00%	1	98.25%
21	0	100.00%	0	98.25%
22	0	100.00%	0	98.25%
23	0	100.00%	0	98.25%
24	0	100.00%	0	98.25%
25	0	100.00%	0	98.25%
26	0	100.00%	2	99.13%
27	0	100.00%	2	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	73		229	



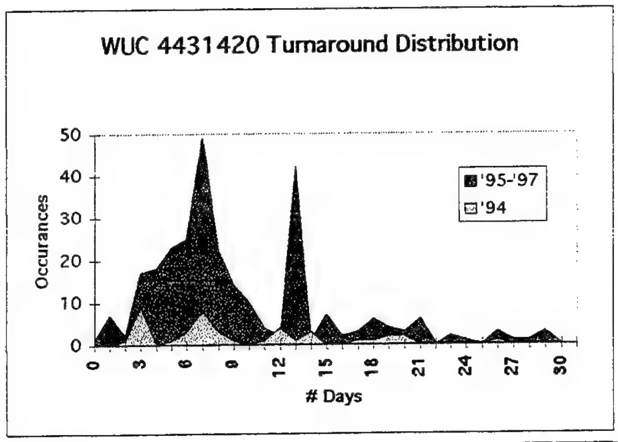


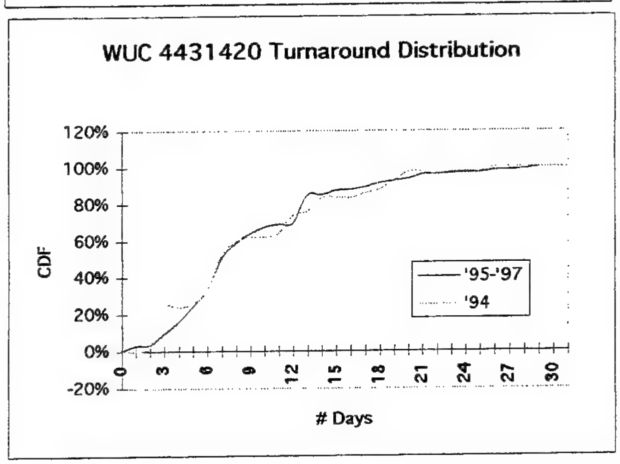
WC: 650
WUC: 4431420

Data Under 30 Days ONLY
F-18 STROBE LIGHT POWER SUPPLY (SLPS)
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	42	9.381	2	26	24	5.951
1995	89	9.258	2	27	25	4.332
1996	122	9.549	0	29	29	6.416
1997	68	9.279	1	29	28	6.212
95-97:	279	9.391	0	29	29	5.760
All Years:	321	9.389	0	29	29	5.776

Bin	Frequency	Cumulative %	Frequency	Cumulative %
0	0	.00%	1	.36%
1	0	.00%	7	2.87%
2	1	2.38%	2	3.58%
3	9	23.81%	17	9.68%
4	0	23.81%	18	16.13%
5	1	26.19%	23	24.37%
6	3	33.33%	25	33.33%
7	8	52.38%	49	50.90%
8	3	59.52%	22	58.78%
9	1	61.90%	14	63.80%
10	0	61.90%	10	67.38%
11	1	64.29%	4	68.82%
12	4	73.81%	2	69.53%
13	1	76.19%	42	84.59%
14	3	83.33%	1	84.95%
15	0	83.33%	7	87.46%
16	0	83.33%	2	88.17%
17	1	85.71%	3	89.25%
18	1	88.10%	6	91.40%
19	2	92.86%	4	92.83%
20	2	97.62%	3	93.91%
21	0	97.62%	6	96.06%
22	0	97.62%	0	96.06%
23	0	97.62%	2	96.77%
24	0	97.62%	1	97.13%
25	0	97.62%	0	97.13%
26	1	100.00%	3	98.21%
27	0	100.00%	1	98.57%
28	0	100.00%	1	98.92%
29	0	100.00%	3	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	42		279	

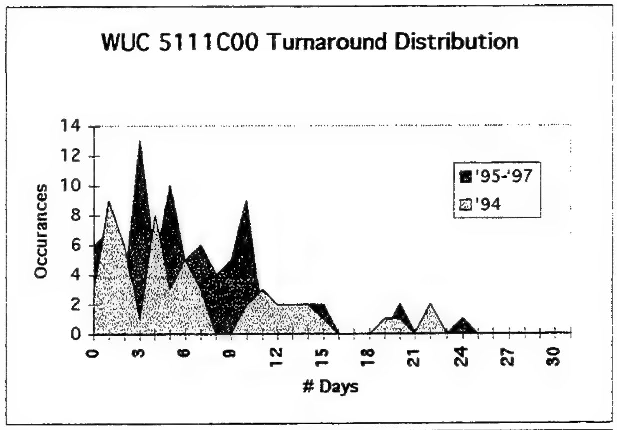


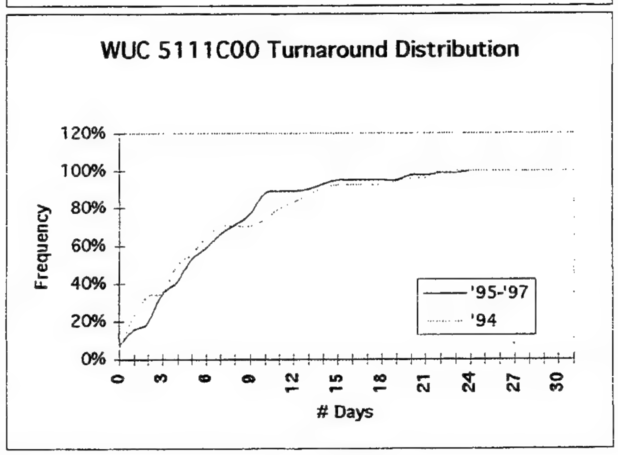


WC:	650	*Data Under 30 Days ONLY*
WUC:	5111C00	F-18 A/B AEU12/A ENGINE PRFM CREW
		BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	54	6.500	0	22	22	5.869
1995	34	6.941	1	24	23	4.824
1996	37	6.541	0	22	22	5.591
1997	12	4.250	0	10	10	3.841
95-97:	83	6.373	0	24	24	5.086
All Years:	137	6.423	0	24	24	5.388

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	3	5.56%	6	7.23%
1	9	22.22%	7	15.66%
2	6	33.33%	3	19.28%
3	1	35.19%	13	34.94%
4	8	50.00%	5	40.96%
5	3	55.56%	10	53.01%
6	5	64.81%	5	59.04%
7	3	70.37%	6	66.27%
8	0	70.37%	4	71.08%
9	0	70.37%	5	77.11%
10	2	74.07%	9	87.95%
11	3	79.63%	1	89.16%
12	2	83.33%	0	89.16%
13	2	87.04%	1	90.36%
14	2	90.74%	2	92.77%
15	1	92.59%	2	95.18%
16	0	92.59%	0	95.18%
17	0	92.59%	0	95.18%
18	0	92.59%	0	95.18%
19	1	94.44%	0	95.18%
20	1	96.30%	2	97.59%
21	0	96.30%	0	97.59%
22	2	100.00%	1	98.80%
23	0	100.00%	0	98.80%
24	0	100.00%	1	100.00%
25	0	100.00%	0	100.00%
26	0	100.00%	0	100.00%
27	0	100.00%	0	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	54		83	



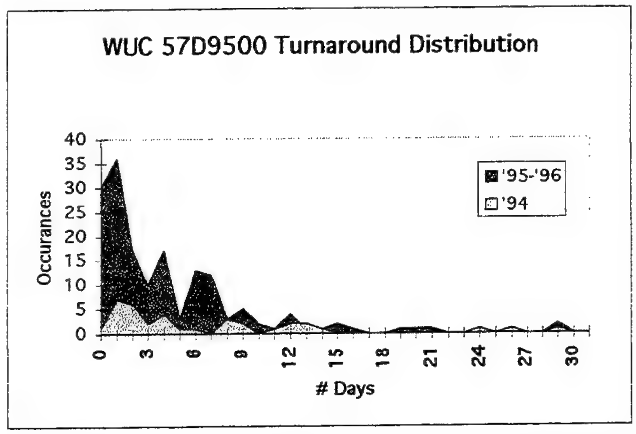


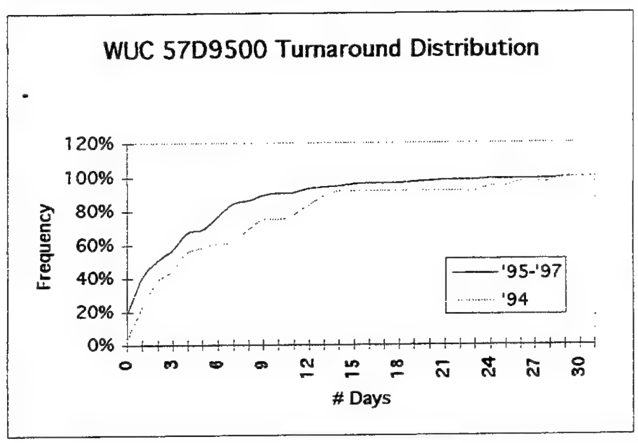
WC: 650
WUC: 57D9500

Data Under 30 Days ONLY
F-18 A/B/C/D CN1511/ASW44 RATE GYROSCOPE
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	36	6.889	0	29	29	7.281
1995	51	6.118	0	24	24	5.317
1996	68	4.456	0	29	29	5.913
1997	45	2.067	0	12	12	3.070
95-97:	164	4.317	0	29	29	5.292
All Years:	200	4.780	0	29	29	5.766

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	1	2.78%	30	18.29%
1	7	22.22%	36	40.24%
2	6	38.89%	17	50.61%
3	2	44.44%	10	56.71%
4	4	55.56%	17	67.07%
5	1	58.33%	3	68.90%
6	1	61.11%	13	76.83%
7	0	61.11%	12	84.15%
8	3	69.44%	3	85.98%
9	2	75.00%	5	89.02%
10	0	75.00%	2	90.24%
11	1	77.78%	1	90.85%
12	2	83.33%	4	93.29%
13	2	88.89%	1	93.90%
14	1	91.67%	1	94.51%
15	0	91.67%	2	95.73%
16	0	91.67%	1	96.34%
17	0	91.67%	0	96.34%
18	0	91.67%	0	96.34%
19	0	91.67%	1	96.95%
20	0	91.67%	1	97.56%
21	0	91.67%	1	98.17%
22	0	91.67%	0	98.17%
23	0	91.67%	0	98.17%
24	1	94.44%	1	98.78%
25	0	94.44%	0	98.78%
26	1	97.22%	0	98.78%
27	0	97.22%	0	98.78%
28	0	97.22%	0	98.78%
29	1	100.00%	2	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	36		164	





WC: 650
WUC: 57D9600

Data Under 30 Days ONLY

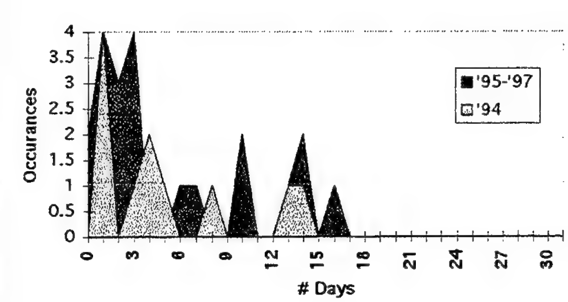
F-18 A/B/C/D CN1512/ASW44 LINE ELECTRICAL ACCELEROMETER

BCM Delete

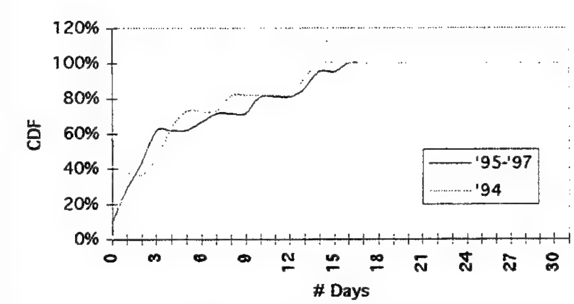
Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	11	5.000	1	14	13	4.733
1995	9	6.889	0	16	16	6.274
1996	8	4.125	0	10	10	3.796
1997	4	4.250	1	13	12	5.852
95-97:	21	5.333	0	16	16	5.276
All Years:	32	5.219	0	16	16	5.021

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	0	.00%	2	9.52%
1	4	36.36%	4	28.57%
2	0	36.36%	3	42.86%
3	1	45.45%	4	61.90%
4	2	63.64%	0	61.90%
5	1	72.73%	0	61.90%
6	0	72.73%	1	66.67%
7	0	72.73%	1	71.43%
8	1	81.82%	0	71.43%
9	0	81.82%	0	71.43%
10	0	81.82%	2	80.95%
11	0	81.82%	0	80.95%
12	0	81.82%	0	80.95%
13	1	90.91%	1	85.71%
14	1	100.00%	2	95.24%
15	0	100.00%	0	95.24%
16	0	100.00%	1	100.00%
17	0	100.00%	0	100.00%
18	0	100.00%	0	100.00%
19	0	100.00%	0	100.00%
20	0	100.00%	0	100.00%
21	0	100.00%	0	100.00%
22	0	100.00%	0	100.00%
23	0	100.00%	0	100.00%
24	0	100.00%	0	100.00%
25	0	100.00%	0	100.00%
26	0	100.00%	0	100.00%
27	0	100.00%	0	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	11		21	

WUC 57D9600 Turnaround Distribution



WUC 4115700 Turnaround Distribution

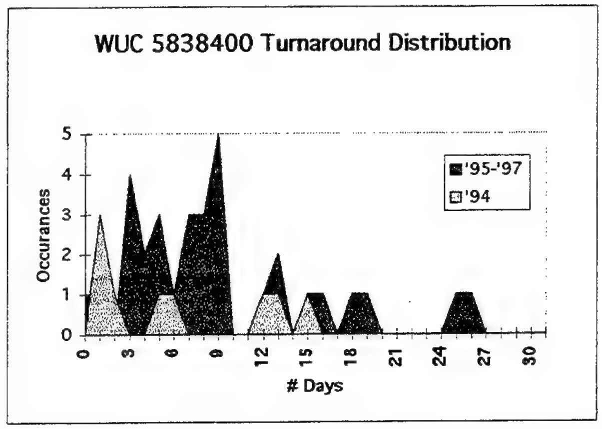


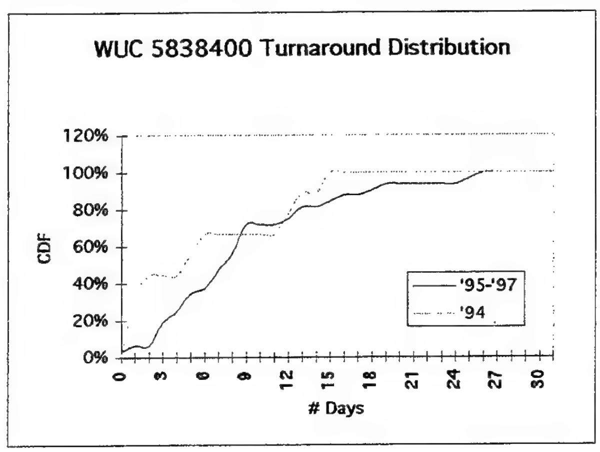
WC:	650
WUC:	5838400

Data Under 30 Days ONLY
F-18 A/B ID2150/ASM612 DIGITAL DISPLAY
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	9	6.222	1	15	14	5.674
1995	5	9.800	4	16	12	4.494
1996	9	6.778	1	19	18	5.167
1997	18	9.944	0	26	26	7.296
95-97:	32	9.031	0	26	26	6.383
All Years:	41	8.415	0	26	26	6.277

Bin	Frequency	Cumulative %	Frequency	Cumulative %
0	0	.00%	1	3.13%
1	3	33.33%	1	6.25%
2	1	44.44%	0	6.25%
3	0	44.44%	4	18.75%
4	0	44.44%	2	25.00%
5	1	55.56%	3	34.38%
6	1	66.67%	1	37.50%
7	0	66.67%	3	46.88%
8	0	66.67%	3	56.25%
9	0	66.67%	5	71.88%
10	0	66.67%	0	71.88%
11	0	66.67%	0	71.88%
12	1	77.78%	1	75.00%
13	1	88.89%	2	81.25%
14	0	88.89%	0	81.25%
15	1	100.00%	1	84.38%
16	0	100.00%	1	87.50%
17	0	100.00%	0	87.50%
18	0	100.00%	1	90.63%
19	0	100.00%	1	93.75%
20	0	100.00%	0	93.75%
21	0	100.00%	0	93.75%
22	0	100.00%	0	93.75%
23	0	100.00%	0	93.75%
24	0	100.00%	0	93.75%
25	0	100.00%	1	96.88%
26	0	100.00%	1	100.00%
27	0	100.00%	0	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	9		32	

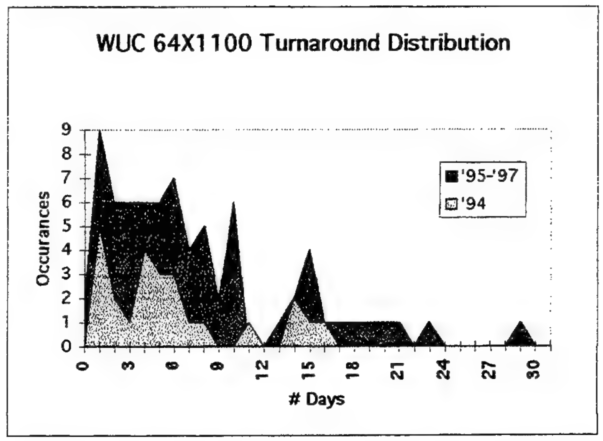


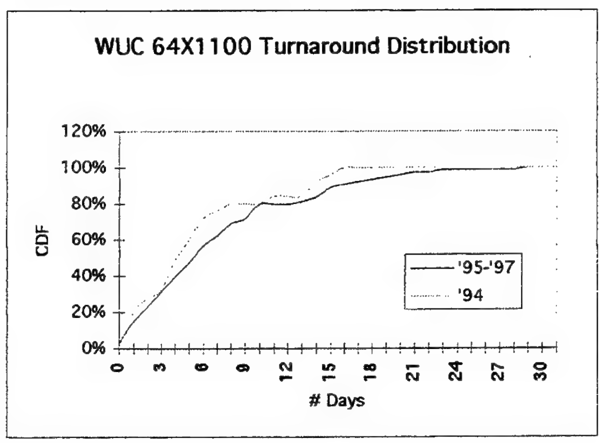


WC:	650		*Data Under 30 Days ONLY*
WUC:	64X1100		F-18 A/B/C/D AM6979/A INTERCOM AMPLIFIER
			BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	25	5.840	1	16	15	4.670
1995	24	9.917	1	29	28	7.003
1996	26	6.615	1	23	22	5.636
1997	24	5.625	0	20	20	5.046
95-97:	74	7.365	0	29	29	6.139
All Years:	99	6.980	0	29	29	5.819

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	0	.00%	2	2.70%
1	5	20.00%	9	14.86%
2	2	28.00%	6	22.97%
3	1	32.00%	6	31.08%
4	4	48.00%	6	39.19%
5	3	60.00%	6	47.30%
6	3	72.00%	7	56.76%
7	1	76.00%	4	62.16%
8	1	80.00%	5	68.92%
9	0	80.00%	2	71.62%
10	0	80.00%	6	79.73%
11	1	84.00%	0	79.73%
12	0	84.00%	0	79.73%
13	0	84.00%	1	81.08%
14	2	92.00%	2	83.78%
15	1	96.00%	4	89.19%
16	1	100.00%	1	90.54%
17	0	100.00%	1	91.89%
18	0	100.00%	1	93.24%
19	0	100.00%	1	94.59%
20	0	100.00%	1	95.95%
21	0	100.00%	1	97.30%
22	0	100.00%	0	97.30%
23	0	100.00%	1	98.65%
24	0	100.00%	0	98.65%
25	0	100.00%	0	98.65%
26	0	100.00%	0	98.65%
27	0	100.00%	0	98.65%
28	0	100.00%	0	98.65%
29	0	100.00%	1	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	25		74	



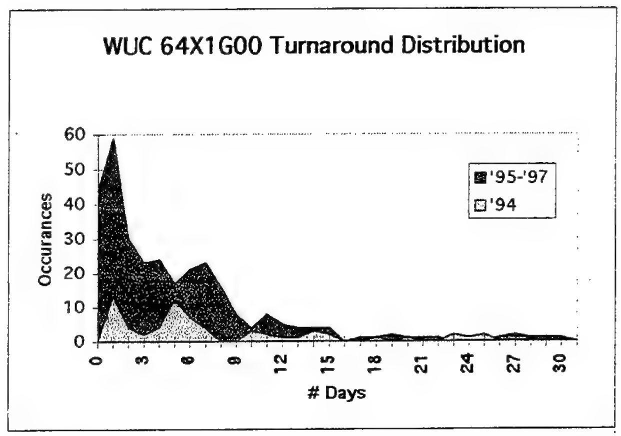


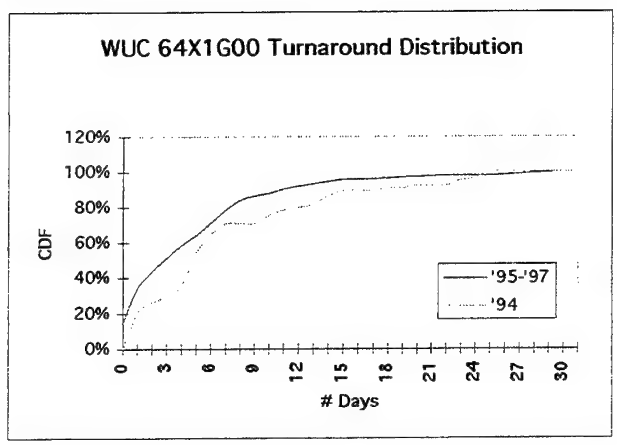
WC:	650
WUC:	64X1G00

Data Under 30 Days ONLY
F-18 A/C/D AM7360/A INTERCOM AMPLIFIER
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	65	7.385	1	25	24	6.633
1995	78	7.385	0	30	30	6.091
1996	136	4.706	0	29	29	4.922
1997	93	3.215	0	28	28	4.850
95-97:	307	4.935	0	30	30	5.436
All Years:	372	5.363	0	30	30	5.729

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	0	.00%	44	14.33%
1	13	20.00%	59	33.55%
2	4	26.15%	30	43.32%
3	2	29.23%	23	50.81%
4	4	35.38%	24	58.63%
5	12	53.85%	17	64.17%
6	7	64.62%	21	71.01%
7	4	70.77%	23	78.50%
8	0	70.77%	16	83.71%
9	0	70.77%	8	86.32%
10	3	75.38%	4	87.62%
11	2	78.46%	8	90.23%
12	1	80.00%	5	91.86%
13	1	81.54%	4	93.16%
14	3	86.15%	4	94.46%
15	2	89.23%	4	95.77%
16	0	89.23%	0	95.77%
17	0	89.23%	1	96.09%
18	1	90.77%	1	96.42%
19	0	90.77%	2	97.07%
20	1	92.31%	1	97.39%
21	0	92.31%	1	97.72%
22	0	92.31%	1	98.05%
23	2	95.38%	0	98.05%
24	1	96.92%	0	98.05%
25	2	100.00%	0	98.05%
26	0	100.00%	1	98.37%
27	0	100.00%	2	99.02%
28	0	100.00%	1	99.35%
29	0	100.00%	1	99.67%
30	0	100.00%	1	100.00%
More	0	100.00%	0	100.00%
	65		307	



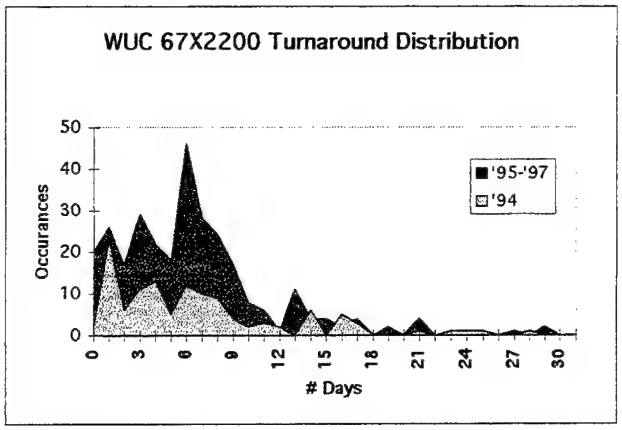


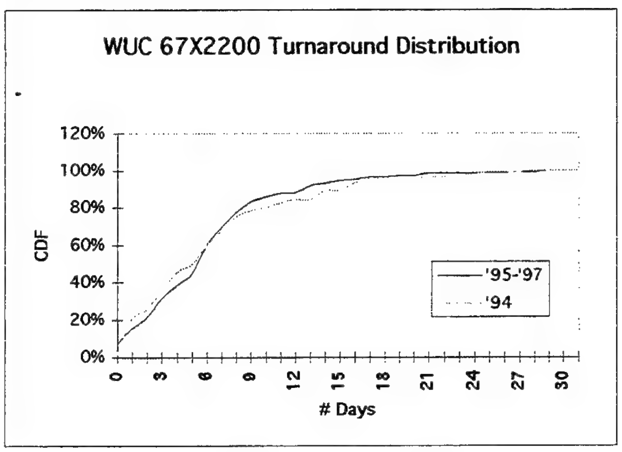
WC: 650
WUC: 67X2200

Data Under 30 Days ONLY
F-18 A/B/C/D C10380/ASQ ELECTRONIC EQUIPMENT
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	121	6.678	0	28	28	5.798
1995	96	7.260	1	27	26	4.361
1996	121	6.496	0	29	29	5.361
1997	80	5.100	0	21	21	5.031
95-97:	297	6.367	0	29	29	5.021
All Years:	418	6.457	0	29	29	5.252

Bin	Frequency	Cumulative %	Frequency	Cumulative %
0	2	1.65%	20	6.73%
1	23	20.66%	26	15.49%
2	6	25.62%	17	21.21%
3	11	34.71%	29	30.98%
4	13	45.45%	22	38.38%
5	5	49.59%	18	44.44%
6	12	59.50%	46	59.93%
7	10	67.77%	28	69.36%
8	9	75.21%	24	77.44%
9	4	78.51%	17	83.16%
10	2	80.17%	8	85.86%
11	3	82.64%	6	87.88%
12	2	84.30%	1	88.22%
13	0	84.30%	11	91.92%
14	6	89.26%	4	93.27%
15	0	89.26%	4	94.61%
16	5	93.39%	2	95.29%
17	3	95.87%	4	96.63%
18	0	95.87%	0	96.63%
19	0	95.87%	2	97.31%
20	0	95.87%	0	97.31%
21	1	96.69%	4	98.65%
22	0	96.69%	0	98.65%
23	1	97.52%	0	98.65%
24	1	98.35%	0	98.65%
25	1	99.17%	1	98.99%
26	0	99.17%	0	98.99%
27	0	99.17%	1	99.33%
28	1	100.00%	0	99.33%
29	0	100.00%	2	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	121		297	



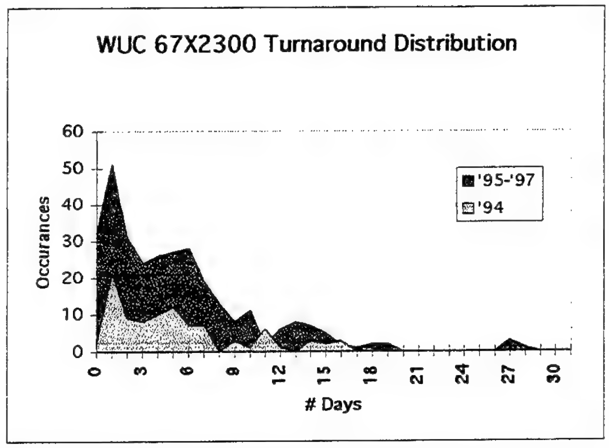


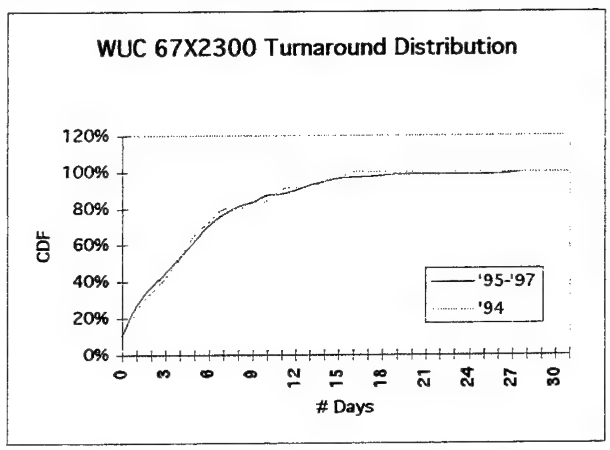
WC: 650
WUC: 67X2300

Data Under 30 Days ONLY
F-18 A/C/D C11919/ASQ ELECTRONIC EQUIPMENT
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	95	5.147	0	16	16	4.235
1995	94	5.447	0	18	18	4.267
1996	122	5.254	0	28	28	5.525
1997	93	4.957	0	18	18	4.967
95-97:	309	5.223	0	28	28	4.989
All Years:	404	5.205	0	28	28	4.818

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	2	2.11%	32	10.36%
1	21	24.21%	51	26.86%
2	9	33.68%	31	36.89%
3	8	42.11%	24	44.66%
4	10	52.63%	26	53.07%
5	12	65.26%	27	61.81%
6	7	72.63%	28	70.87%
7	7	80.00%	19	77.02%
8	0	80.00%	13	81.23%
9	3	83.16%	8	83.82%
10	1	84.21%	11	87.38%
11	6	90.53%	2	88.03%
12	1	91.58%	6	89.97%
13	0	91.58%	8	92.56%
14	3	94.74%	7	94.82%
15	2	96.84%	5	96.44%
16	3	100.00%	2	97.09%
17	0	100.00%	1	97.41%
18	0	100.00%	2	98.06%
19	0	100.00%	2	98.71%
20	0	100.00%	0	98.71%
21	0	100.00%	0	98.71%
22	0	100.00%	0	98.71%
23	0	100.00%	0	98.71%
24	0	100.00%	0	98.71%
25	0	100.00%	0	98.71%
26	0	100.00%	0	98.71%
27	0	100.00%	3	99.68%
28	0	100.00%	1	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	95		309	



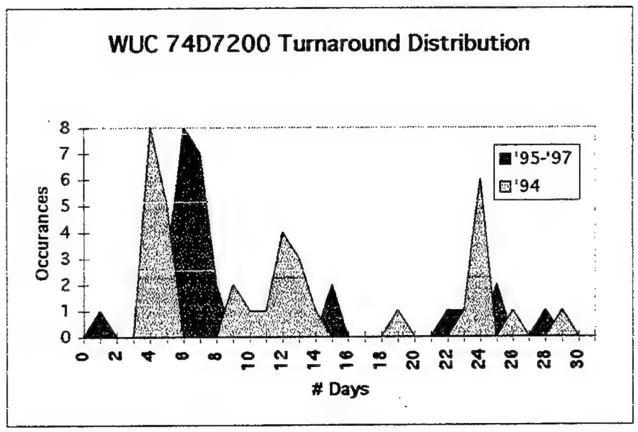


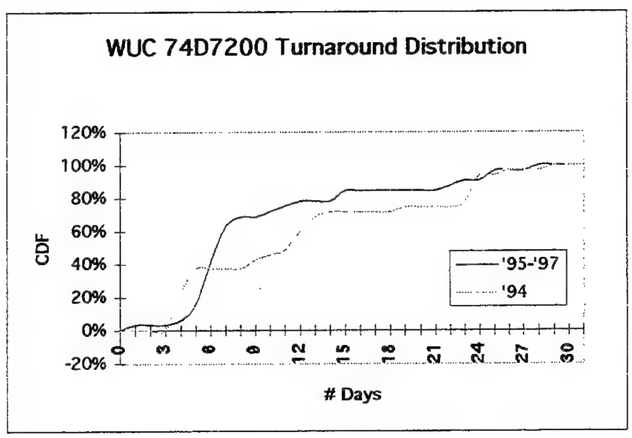
WC: 650
WUC: 74D7200

Data Under 30 Days ONLY
F-18 A/C/D J3656/ASQ173 INTERCONNECT
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	35	12.514	4	29	25	8.219
1995	1	8.000	8	8	0	na
1996	20	9.500	1	25	24	7.207
1997	11	11.000	6	28	22	7.253
95-97:	32	9.969	1	28	27	7.032
All Years:	67	11.299	1	29	28	7.724

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	0	.00%	0	.00%
1	0	.00%	1	3.13%
2	0	.00%	0	3.13%
3	0	.00%	0	3.13%
4	8	22.86%	1	6.25%
5	5	37.14%	3	15.63%
6	0	37.14%	8	40.63%
7	0	37.14%	7	62.50%
8	0	37.14%	2	68.75%
9	2	42.86%	0	68.75%
10	1	45.71%	1	71.88%
11	1	48.57%	1	75.00%
12	4	60.00%	1	78.13%
13	3	68.57%	0	78.13%
14	1	71.43%	0	78.13%
15	0	71.43%	2	84.38%
16	0	71.43%	0	84.38%
17	0	71.43%	0	84.38%
18	0	71.43%	0	84.38%
19	1	74.29%	0	84.38%
20	0	74.29%	0	84.38%
21	0	74.29%	0	84.38%
22	0	74.29%	1	87.50%
23	1	77.14%	1	90.63%
24	6	94.29%	0	90.63%
25	0	94.29%	2	96.88%
26	1	97.14%	0	96.88%
27	0	97.14%	0	96.88%
28	0	97.14%	1	100.00%
29	1	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	35		32	



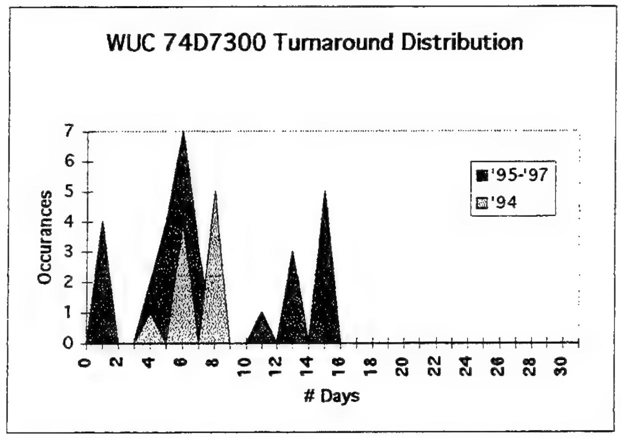


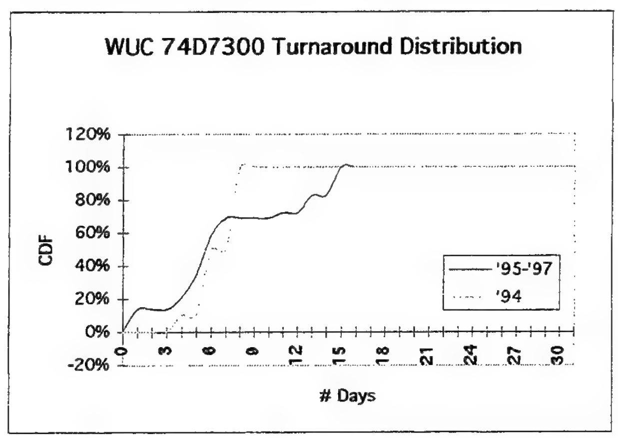
WC:	650
WUC:	74D7300

Data Under 30 Days ONLY
F-18 A/C/D TG244/ASQ173 CAMERA DRIVE
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	10	6.800	4	8	4	1.398
1995	18	8.722	4	15	11	4.417
1996	4	3.000	1	6	5	2.449
1997	7	7.286	1	13	12	5.187
95-97:	29	7.586	1	15	14	4.702
All Years:	39	7.385	1	15	14	4.108

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	0	.00%	0	.00%
1	0	.00%	4	13.79%
2	0	.00%	0	13.79%
3	0	.00%	0	13.79%
4	1	10.00%	2	20.69%
5	0	10.00%	4	34.48%
6	4	50.00%	7	58.62%
7	0	50.00%	3	68.97%
8	5	100.00%	0	68.97%
9	0	100.00%	0	68.97%
10	0	100.00%	0	68.97%
11	0	100.00%	1	72.41%
12	0	100.00%	0	72.41%
13	0	100.00%	3	82.76%
14	0	100.00%	0	82.76%
15	0	100.00%	5	100.00%
16	0	100.00%	0	100.00%
17	0	100.00%	0	100.00%
18	0	100.00%	0	100.00%
19	0	100.00%	0	100.00%
20	0	100.00%	0	100.00%
21	0	100.00%	0	100.00%
22	0	100.00%	0	100.00%
23	0	100.00%	0	100.00%
24	0	100.00%	0	100.00%
25	0	100.00%	0	100.00%
26	0	100.00%	0	100.00%
27	0	100.00%	0	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	10		29	

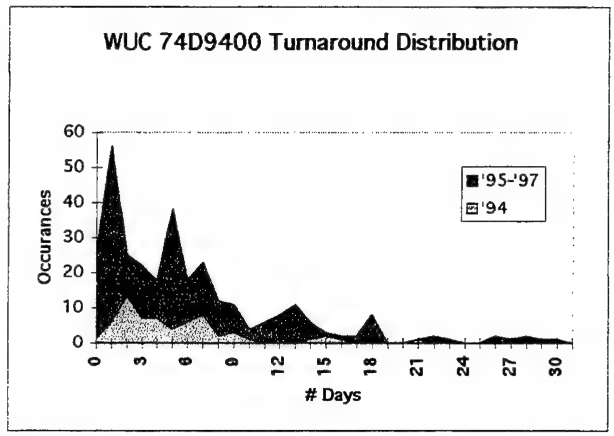


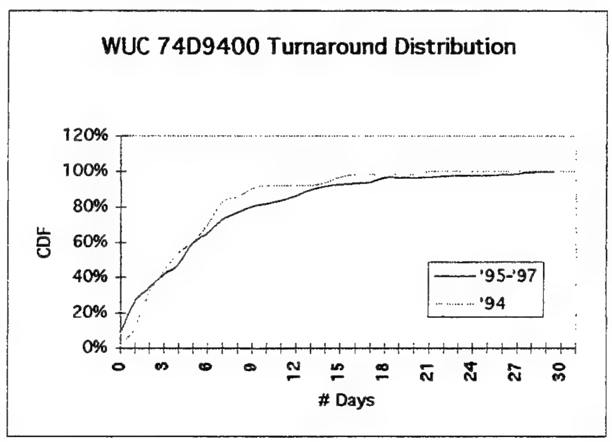


WC:	650	*Data Under 30 Days ONLY*
WUC:	74D9400	F-18 A/C/D PP7567/AAS38 POWER SUPPLY
		BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	63	5.190	0	21	21	4.130
1995	103	7.350	0	28	28	4.775
1996	80	6.238	0	30	30	7.860
1997	127	4.787	0	18	18	5.064
95-97:	310	6.013	0	30	30	5.916
All Years:	373	5.874	0	30	30	5.658

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	1	1.59%	26	8.39%
1	6	11.11%	56	26.45%
2	13	31.75%	25	34.52%
3	7	42.86%	22	41.61%
4	7	53.97%	18	47.42%
5	4	60.32%	38	59.68%
6	6	69.84%	18	65.48%
7	8	82.54%	23	72.90%
8	2	85.71%	12	76.77%
9	3	90.48%	11	80.32%
10	1	92.06%	4	81.61%
11	0	92.06%	6	83.55%
12	0	92.06%	8	86.13%
13	0	92.06%	11	89.68%
14	1	93.65%	6	91.61%
15	2	96.83%	3	92.58%
16	1	98.41%	2	93.23%
17	0	98.41%	2	93.87%
18	0	98.41%	8	96.45%
19	0	98.41%	0	96.45%
20	0	98.41%	0	96.45%
21	1	100.00%	1	96.77%
22	0	100.00%	2	97.42%
23	0	100.00%	1	97.74%
24	0	100.00%	0	97.74%
25	0	100.00%	0	97.74%
26	0	100.00%	2	98.39%
27	0	100.00%	1	98.71%
28	0	100.00%	2	99.35%
29	0	100.00%	1	99.68%
30	0	100.00%	1	100.00%
More	0	100.00%	0	100.00%
	63		310	



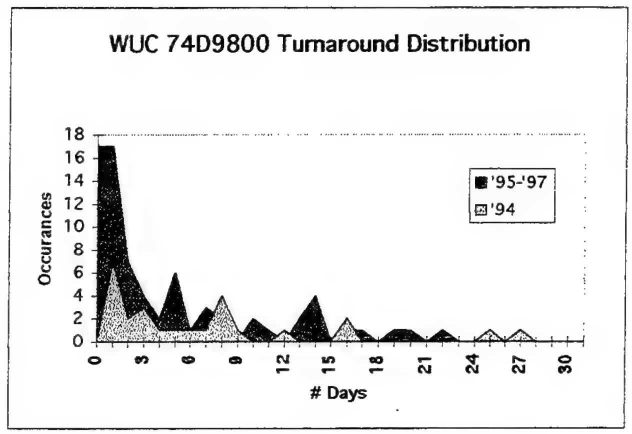


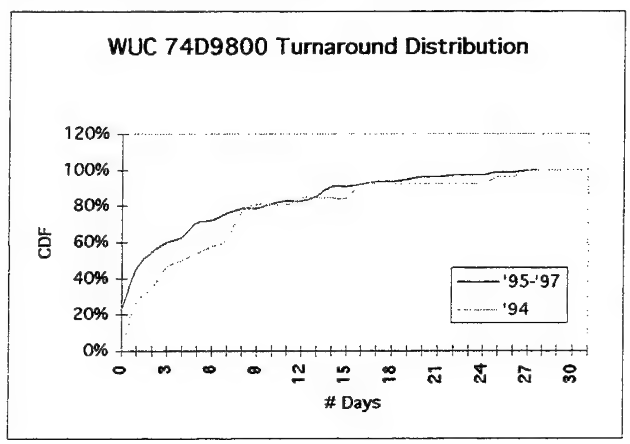
WC: 650
WUC: 74D9800

Data Under 30 Days ONLY
F-18 A/C AM7040/AAS38 ROLL DRIVE A
BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	26	6.885	1	27	26	7.163
1995	23	6.609	0	22	22	6.854
1996	17	4.765	0	27	27	6.906
1997	35	4.286	0	25	25	6.257
95-97:	75	5.107	0	27	27	6.581
All Years:	101	5.564	0	27	27	6.745

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	0	.00%	17	22.67%
1	7	26.92%	17	45.33%
2	2	34.62%	7	54.67%
3	3	46.15%	4	60.00%
4	1	50.00%	2	62.67%
5	1	53.85%	6	70.67%
6	1	57.69%	1	72.00%
7	1	61.54%	3	76.00%
8	4	76.92%	2	78.67%
9	1	80.77%	0	78.67%
10	0	80.77%	2	81.33%
11	0	80.77%	1	82.67%
12	1	84.62%	0	82.67%
13	0	84.62%	2	85.33%
14	0	84.62%	4	90.67%
15	0	84.62%	0	90.67%
16	2	92.31%	1	92.00%
17	0	92.31%	1	93.33%
18	0	92.31%	0	93.33%
19	0	92.31%	1	94.67%
20	0	92.31%	1	96.00%
21	0	92.31%	0	96.00%
22	0	92.31%	1	97.33%
23	0	92.31%	0	97.33%
24	0	92.31%	0	97.33%
25	1	96.15%	1	98.67%
26	0	96.15%	0	98.67%
27	1	100.00%	1	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	26		75	

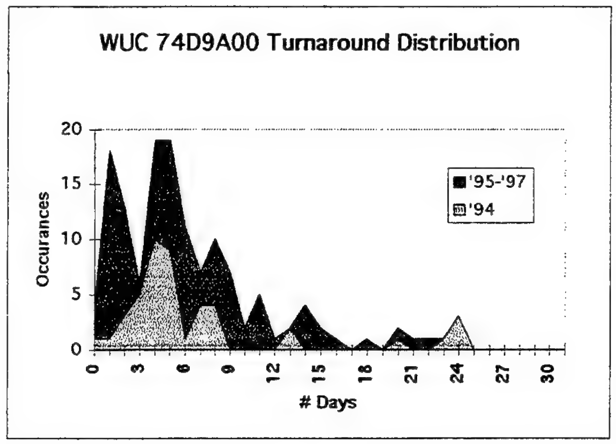


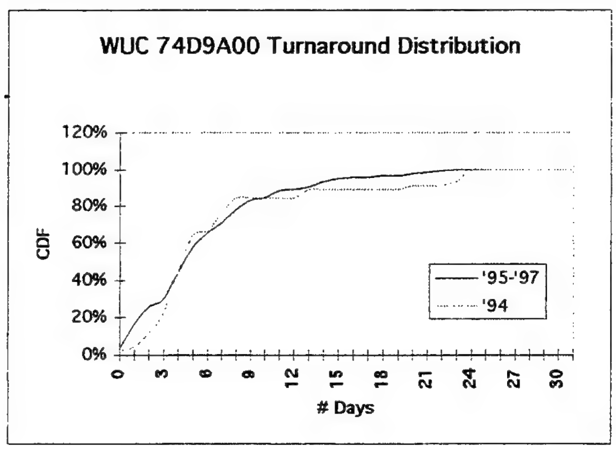


WC:	650	*Data Under 30 Days ONLY*
WUC:	74D9A00	F-18 A/C C10681/AAS38 TEMPERATURE
		BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	45	6.978	0	24	24	6.279
1995	46	6.783	1	21	20	4.939
1996	44	5.295	0	23	23	4.608
1997	47	6.064	0	22	22	4.923
95-97:	137	6.058	0	23	23	4.832
All Years:	182	6.286	0	24	24	5.224

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	1	2.22%	4	2.92%
1	1	4.44%	18	16.06%
2	3	11.11%	13	25.55%
3	5	22.22%	6	29.93%
4	10	44.44%	19	43.80%
5	9	64.44%	19	57.66%
6	1	66.67%	11	65.69%
7	4	75.56%	7	70.80%
8	4	84.44%	10	78.10%
9	0	84.44%	7	83.21%
10	0	84.44%	2	84.67%
11	0	84.44%	5	88.32%
12	0	84.44%	1	89.05%
13	2	88.89%	2	90.51%
14	0	88.89%	4	93.43%
15	0	88.89%	2	94.89%
16	0	88.89%	1	95.62%
17	0	88.89%	0	95.62%
18	0	88.89%	1	96.35%
19	0	88.89%	0	96.35%
20	1	91.11%	2	97.81%
21	0	91.11%	1	98.54%
22	0	91.11%	1	99.27%
23	1	93.33%	1	100.00%
24	3	100.00%	0	100.00%
25	0	100.00%	0	100.00%
26	0	100.00%	0	100.00%
27	0	100.00%	0	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	45		137	

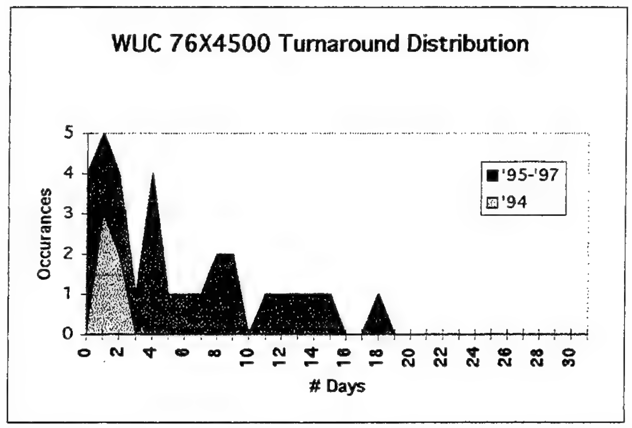


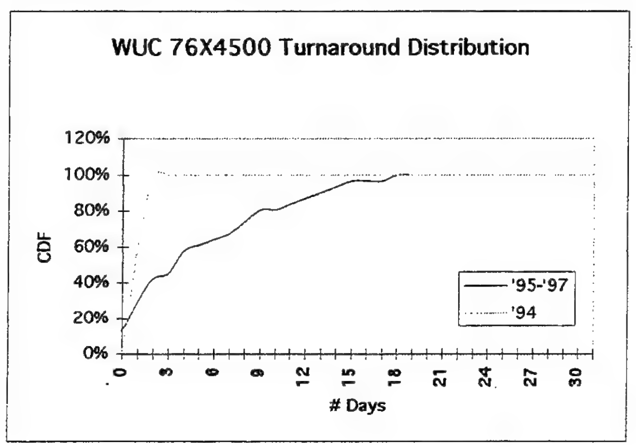


WC:	650	*Data Under 30 Days ONLY*
WUC:	76X4500	F-18 A/C MX9965/A INTERFERENCE BLANKER
		BCM Delete

Year:	# Actions	Mean Days	Min Days	Max Days	RNG Days:	StdDev Days:
1994	5	1.400	1	2	1	0.548
1995	4	8.750	5	15	10	4.349
1996	22	5.318	0	18	18	5.286
1997	5	3.000	0	9	9	3.742
95-97:	31	5.387	0	18	18	5.077
All Years:	36	4.833	0	18	18	4.908

Bin	*Frequency*	*Cumulative %*	*Frequency*	*Cumulative %*
0	0	.00%	4	12.90%
1	3	60.00%	5	29.03%
2	2	100.00%	4	41.94%
3	0	100.00%	1	45.16%
4	0	100.00%	4	58.06%
5	0	100.00%	1	61.29%
6	0	100.00%	1	64.52%
7	0	100.00%	1	67.74%
8	0	100.00%	2	74.19%
9	0	100.00%	2	80.65%
10	0	100.00%	0	80.65%
11	0	100.00%	1	83.87%
12	0	100.00%	1	87.10%
13	0	100.00%	1	90.32%
14	0	100.00%	1	93.55%
15	0	100.00%	1	96.77%
16	0	100.00%	0	96.77%
17	0	100.00%	0	96.77%
18	0	100.00%	1	100.00%
19	0	100.00%	0	100.00%
20	0	100.00%	0	100.00%
21	0	100.00%	0	100.00%
22	0	100.00%	0	100.00%
23	0	100.00%	0	100.00%
24	0	100.00%	0	100.00%
25	0	100.00%	0	100.00%
26	0	100.00%	0	100.00%
27	0	100.00%	0	100.00%
28	0	100.00%	0	100.00%
29	0	100.00%	0	100.00%
30	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%
	5		31	





WUC	Total Qty ('94-'97)		Avg TAT '94	Avg TAT '95-'97
4115700	308		4.438	4.341
4431420	373		9.381	9.391
5111C00	152		6.500	6.373
57D9500	231		6.889	4.317
57D9600	36		5.000	5.333
5838400	44		6.222	9.031
64X1100	119		5.840	7.365
64X1G00	406		7.385	4.935
67X2200	477		6.678	6.367
67X2300	428		5.147	5.223
74D7200	83		12.514	9.969
74D7300	47		6.800	7.586
74D9400	440		5.190	6.013
74D9800	114		6.885	5.107
74D9A00	208		6.978	6.058
76X4500	38		1.400	5.387
	3504			

$n_p=$ 3504
$\sum D=$ 1487.907
$\sum D\text{^}2=$ 6650.984

$D_{bar}=$ $\sum D/n_p$
0.4246

$S_{D}=$ $((\sum D\text{^}2-((\sum D)\text{^}2/n_p))/(n_p-1))\text{^}0.5$
1.311

$S_{Dbar}=$ $S_D/(n_p)\text{^}0.5$
0.022

Desired C.L.= 95%

Lower Limit $D_{bar}- S_{Dbar}* t_{\alpha/2}$
0.381

Upper Limit $D_{bar}+ S_{Dbar}* t_{\alpha/2}$
0.468

student *t* value

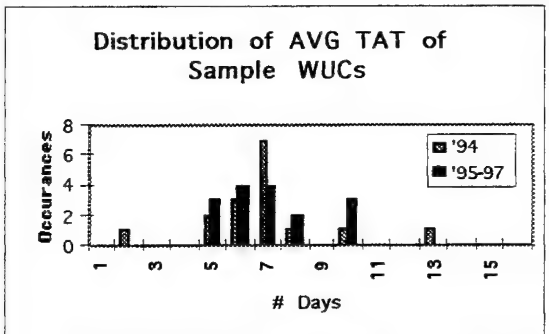
C.L.	$t_{\alpha/2}$
95%	1.961

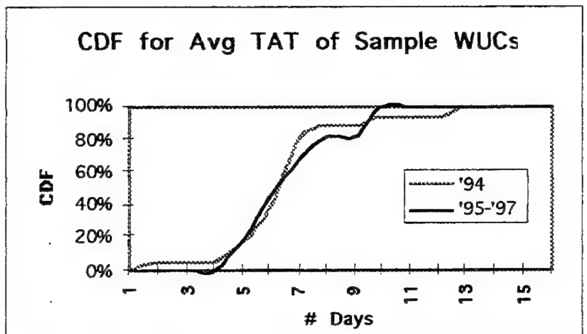
TAT μ shift between populations ('94 vs. '95-'97)
Weighted by Total Quantity Repairs for All Years

The 95% confidence interval is:
$0.381 \leq \mu_1 - \mu_2 \leq 0.468$

APPENDIX C. TAT DISTRIBUTION

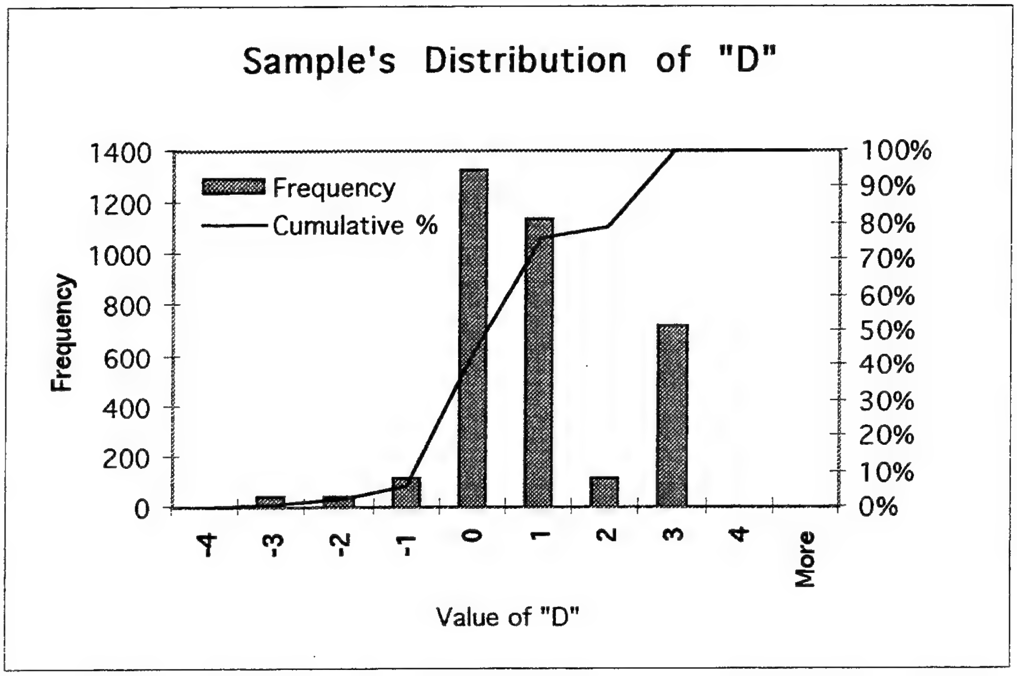
	'94		'95-'97	
Avg TAT	Frequency	Cumulative %	Frequency	Cumulative %
1	0	.00%	0	.00%
2	1	6.25%	0	.00%
3	0	6.25%	0	.00%
4	0	6.25%	0	.00%
5	2	18.75%	3	18.75%
6	3	37.50%	4	43.75%
7	7	81.25%	4	68.75%
8	1	87.50%	2	81.25%
9	0	87.50%	0	81.25%
10	1	93.75%	3	100.00%
11	0	93.75%	0	100.00%
12	0	93.75%	0	100.00%
13	1	100.00%	0	100.00%
14	0	100.00%	0	100.00%
15	0	100.00%	0	100.00%
More	0	100.00%	0	100.00%





Assumption of Normal Distribution is Satisfied for both populations.

Sample D Value	Frequency	Cumulative %
- 4	0	.00%
- 3	38	1.08%
- 2	44	2.34%
- 1	119	5.74%
0	1325	43.53%
1	1144	76.19%
2	114	79.45%
3	720	100.00%
4	0	100.00%
More	0	100.00%
	3504	



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10. Officer In Charge 1
NAESU Detachment Lemoore
Hanger 5, 3rd Floor
Naval Air Station Lemoore
Lemoore, CA 93246
Attn: M. McClelland

11. Dr. David V. Lamm, Code SM/LT 4
Department of Systems Management
Naval Postgraduate School
Monterey, CA 93943-5100

12. Professor K. L. Terasawa, Code SM/KT 1
Department of Systems Management
Naval Postgraduate School
Monterey, CA 93943-5100

13. Professor Keebom Kang, Code SM/KK 1
Department of Systems Management
Naval Postgraduate School
Monterey, CA 93943-5100

14. Commander.. 1
Attn: PAE-Major Brad E. Valdyke
MARCORSYSCOM
2033 Barnett Avenue, Suite 315
Quantico, VA 22134-5010